Northern Alberta Geothermal Potential Mapping Project – Final Report

February, 2019

Northern Alberta Development Council

ALBERTA COMMUNITY AND CO-OPERATIVE ASSOCIATION

Background:

On March 28 and March 30, 2017, the Northern Alberta Development Council (NADC) hosted the Energizing the North Seminars in Athabasca and Peace River, respectively. The focus of the Seminars was to present opportunities for economic diversification and greater energy self-sufficiency in northern communities. The conference raised awareness of the potential of renewable energy sources such as geothermal for northern communities.

With support from the NADC, the Alberta Community & Co-operatives Association (ACCA) prepared a Community Energy Cooperative Toolkit that defined renewable community energy, highlighted several renewable energy funding programs, defined the types of cooperatives, provided the four developmental stages of community energy cooperatives, and offered community energy case studies.

Resulting from the outcomes of this partnership, in December 2017 the NADC provided the ACCA grant funding to conduct a feasibility study on geothermal energy in northern Alberta.

ACCA contracted Terrapin Geothermics Inc. to conduct a high-level geothermal resource evaluation for a representative sampling of forty two northern Alberta communities over a five month period.

The focus of this project was to create location-specific research reports that provided high-level technical overviews of geothermal resource potential, considering both the potential temperatures to be found and unique geological considerations in the targeted communities.

One of the primary objectives was to provide all sub-regions with guidance as to the comparative quality of their geothermal resource, and recommend future research focus areas should they be keen to develop the geothermal resource in their region.

Purpose of the Report

Alberta is in a unique position to achieve long-term success in the geothermal industry due to the industry understanding of down-hole drilling activities, sub-surface safety, and access to skilled labour. Northern Alberta possesses a significant portion of the deep (below 2,500 metre) wells in the province, making it ideal for geothermal development.

Geothermal interest in the province has increased over the last few years for several reasons including: improved available data; advances in technology; recognition of the possible opportunity to re-use of inactive oil and gas wells; and the province's transition to a lower carbon future.

The Alberta government is developing a geothermal policy and has recently conducted engagement sessions with stakeholders. Currently, projects are being reviewed on a case-by-case basis.

Shallow geothermal, also known as geo-exchange, currently exists in Alberta on a small scale, such as for household use, but not for large-scale commercial application.

The research in this report identifies types of viable projects (power production, direct use, or direct heat) while also encouraging the onset of a geothermal market in northern Alberta by providing accurate data to potential developers.

Thirty one of the evaluated areas demonstrated suitable temperatures and basic geological factors to support further investigation into direct use opportunities and twelve areas were identified as containing suitable temperatures and geological factors for power generation.

This final report, including individual assessments for each of the studied communities, will be made available online to be used by planners, economic development officers, municipalities, industry, and community groups interested in the geothermal potential in their regions.

What is Geothermal Energy

Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south.

Geothermal energy developments can be used for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource. In general, the projects you can develop in this industry break down into a few main categories:

1. Geo-Exchange: A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through

standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.

2. Direct Heat Use. Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

3. Electricity Generation. Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.

The region specific report has analyzed each region in northern Alberta's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration.

This report is focused exclusively on temperature mapping and is a desktop study that uses pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in each region.

Attachments

- Mapping Project Final Report

Terrapin Geothermics Inc.

Northern Alberta Geothermal Potential Mapping - Final Report

Document# TGI-2018-ACCA-001

Table of Contents

1.0 Executive Summary

A key issue for communities in determining their renewable energy development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin was contracted to conduct a high-level geothermal resource evaluation for a representative sampling of northern Alberta communities. The focus of this project was to create location-specific research reports that provided a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the targeted communities. One of the primary objectives in conducting this work was to provide all sub-regions with guidance as to the comparative quality of their geothermal resource, and recommended future research focus areas should they be keen to develop the geothermal resource in their region.

Terrapin conducted this work over a 5-month period through Winter and Spring of 2018. Over the course of this work, it has been identified that all 42 studied northern communities demonstrate the potential for geo-exchange activities. 31 areas demonstrated suitable temperatures and basic geological factors to support further investigation into direct use opportunities. Terrapin identified 12 areas as containing suitable temperatures and geological factors for power generation (see page 5 of this summary).

Terrapin is happy to present the findings of these studies to any community that is interested/at any events where studied municipalities will be present. Determining whether to pursue a geothermal project is dependent on the ambition/ability/capital availability of each distinct community.

2.0 Introduction and Scope

Having previously conducted geothermal resource assessments for two northern Alberta municipalities, Terrapin was intrigued by the potential geothermal opportunities within the remainder of northern Alberta. This project would facilitate a high-level understanding of the geothermal resource potential of these territories in order to investigate and evaluate an opportunity for development. Specific project scope was as follows:

1. Define geothermal resources and provide a high-level understanding of geothermal energy uses.
2. Provide a high-level understanding of the specific geothermal resource in a selected group of municipalities.
   a. This list of communities was restricted to all Counties/Municipal Districts/Regional Municipalities and municipalities with population greater than 1500 people, for which this work had not already been completed.
   b. Studies were restricted to areas within a 25km diameter circle for Towns and Cities. All other study areas were restricted to 50km diameter circle.
   c. Communities that met the population threshold but did not contain any data points from which to work were excluded.
3. Recommend future geothermal studies and/or geothermal development opportunities based on the comparative quality of the geothermal resource.
4. Provide technical reports for all identified communities.

3.0 Geothermal Results

Terrapin conducted high-level, desktop studies of a number of northern Alberta municipalities. The detailed technical results and geothermal explainer document have been provided for all mapped areas. Presented below is a chart demonstrating the most promising geothermal applications in each area:

Study Area	Geo-exchange	Direct Use	Power Generation
Athabasca County	✓	✓	
Athabasca	✓	✓	
Beaverlodge	✓	✓	
Big Lakes County	✓	✓	✓
Birch Hills County	✓	✓	
Bonnyville	✓		
Clear Hills County	✓	✓	✓
Cold Lake	✓		
County of Northern Lights	✓	✓	✓
County of St. Paul	✓		
Fairview	✓	✓	
Grande Cache	✓	✓	
Grande Prairie	✓	✓	✓
Grimshaw	✓		
High Level	✓		
High Prairie	✓	✓	
Lac La Biche County	✓		
Manning	✓	✓	
M.D. of Bonnyville	✓		
M.D. of Fairview	✓	✓	
M.D. of Lesser Slave River	✓	✓	✓
M.D. of Opportunity	✓	✓	✓
M.D. of Peace	✓	✓	
M.D. of Smoky River	✓	✓	
M.D. of Spirit River	✓	✓	✓
Mackenzie County	✓	✓	
Northern Sunrise County	✓	✓	
Peace River	✓	✓	
Peavine Metis Settlement	✓		
Regional Municipality of Wood Buffalo	✓		
Saddle Hills County	✓	✓	
Saddle Lake #125	✓	✓	
Sexsmith	✓	✓	
Smoky Lake County	✓		
Slave Lake	✓	✓	✓
St. Paul	✓		
Swan Hills	✓	✓	✓
Wabasca (South)	✓	✓	✓
Wabasca #166-166D	✓	✓	
Wembley	✓	✓	
Whitecourt	✓	✓	✓
Woodlands County	✓	✓	✓

4.0 Conclusion and Future Work

Over the course of this engagement, a number of compelling opportunities presented themselves in some member territories. While the desktop, high-level understanding of the studied municipalities' geothermal potential has been developed to a reasonable point of confidence, additional work will be needed across a few key areas including:

1. Presenting the results of these studies to all studied northern Alberta communities
2. Developing a detailed understanding of the geothermal resource potential in the identified high-opportunity (power-generation and direct-use) areas
3. Establishing an understanding of the development needs and/or wants of studied municipalities
4. Developing an understanding of heat loads and potential offtakes in the northern Alberta regions (i.e. large industrial facilities and/or municipal facilities such as recreation centers)
5. Exploration of additional grant and subsidy opportunities available to geothermal development and applications to relevant programs on behalf of interested municipalities.

September 25, 2018

Geothermal Analysis

Athabasca County

Study by Terrapin Geothermics

terrapin

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above 0^oC.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.

Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.

More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

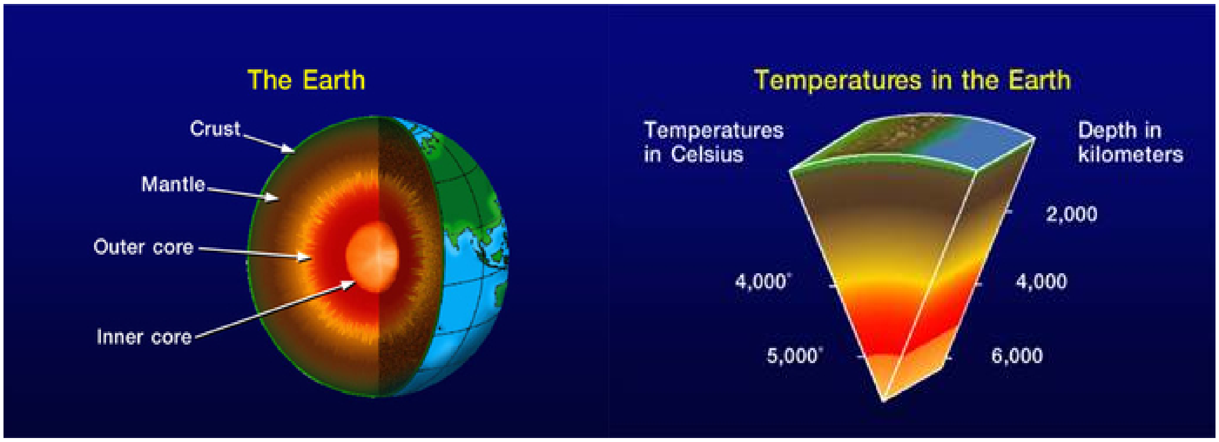
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

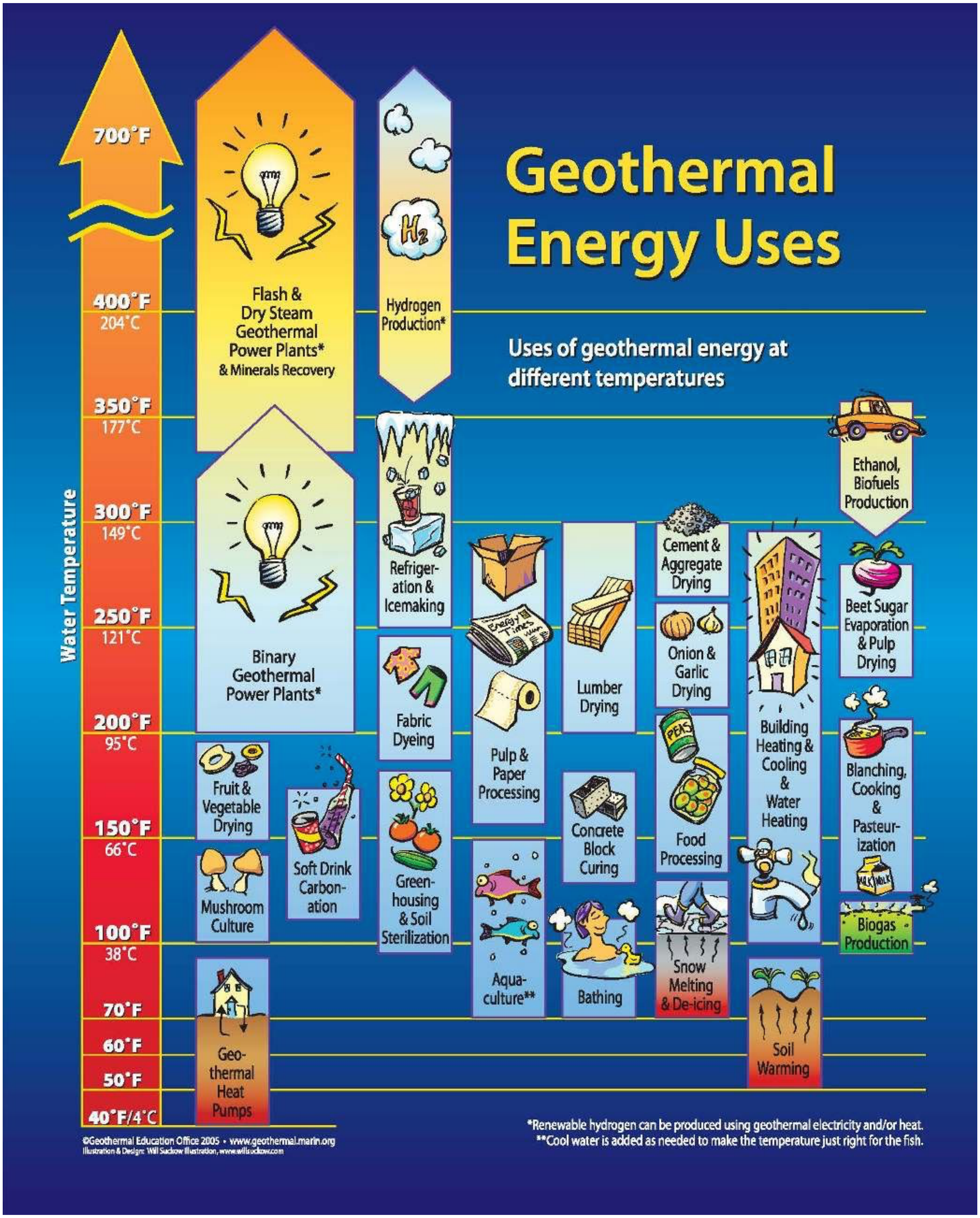
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180^{o}C and above), medium (100-180^{o}C), and low (80-100^{o}C) temperature resources with fluids under 80^{o}C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235^{o}C or above); flash plants (turning geothermal fluids of at least 150^{o}C into steam to drive a turbine); and binary power plants (using hot waters above 80^{o}C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180^{o}C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

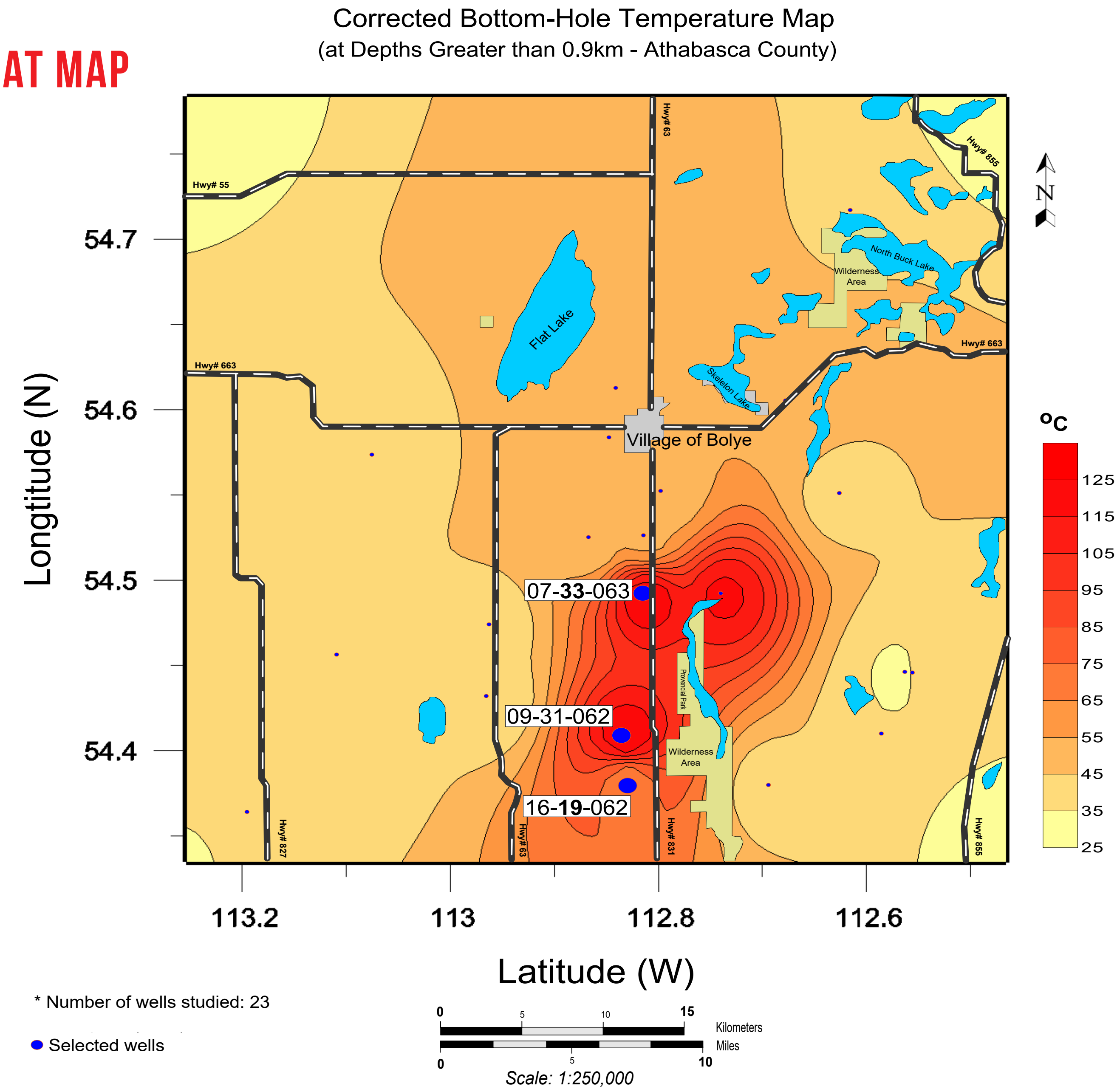
The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

RESEARCH RESULTS: ATHABASCA COUNTY

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

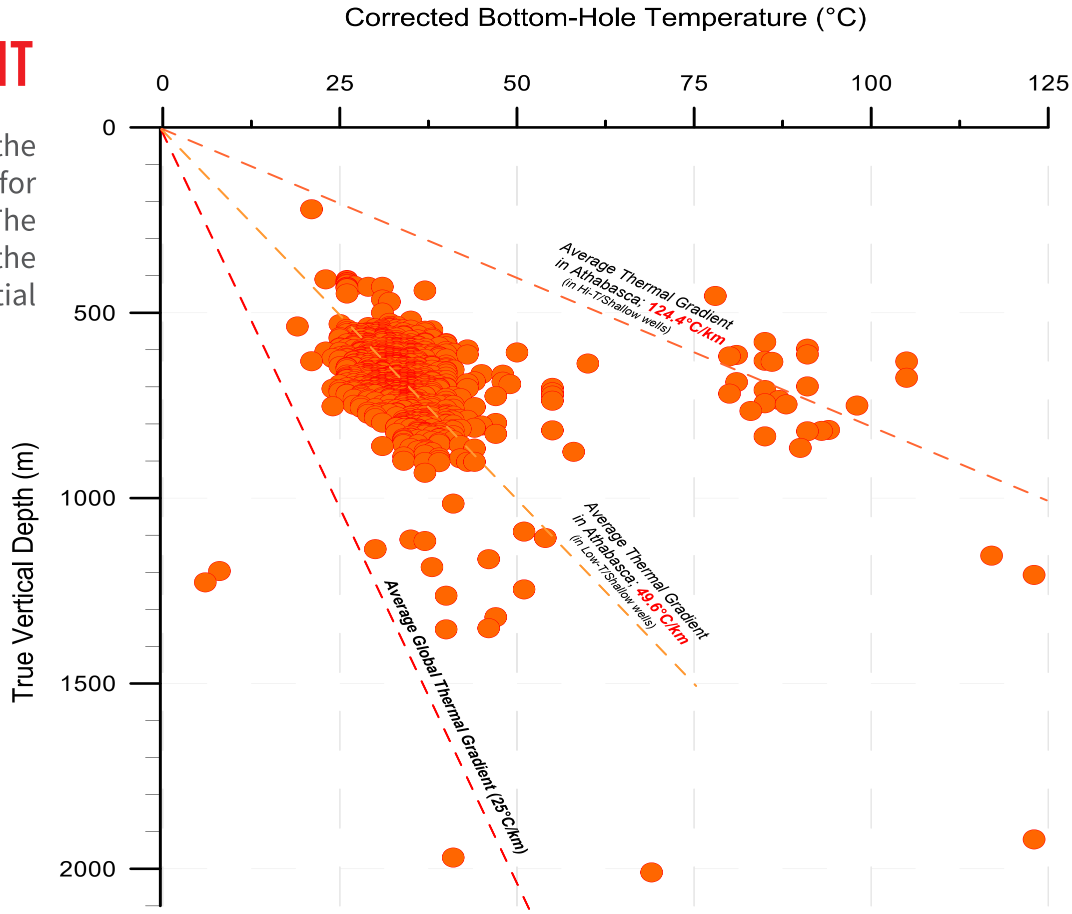
HEAT MAP



RESEARCH RESULTS: ATHABASCA COUNTY

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 3 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Leduc F. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/16-19-062-19W4/00	2008.9	-1179	69	90	Mantol Petrl Lmtd
100/09-31-062-19W4/00	1919.9	-1090	123	150	Devon Cda Corp
100/07-33-063-19W4/00	1206.5	-376.6	123	150	Payne Bryan W Ex

KEY TAKEAWAYS

- There are two potential geothermal formations in the study area: the **Leduc** formation and the **Watt Mountain** formation.
- The majority of wells in the study area have been drilled to a depth of less than **1400m**.
- The average thermal gradient in the study area is **49.6°C/km**. This is almost **100%** better than the global average.
- There is potential for **direct use** opportunities in the study area.

RECOMMENDATION & NOTES

Our research activities in Athabasca County identified strong temperature readings south of the Village of Boyle. Our research also identified incredibly thick (227 and 500m) and relatively shallow (830 and 1392m depth) geological formations with the potential to contain large amounts of geothermal fluids underlying the study area. These two factors are indicative of an area with strong heat-use opportunities. We recommend that the County expand the study area and undertake temperature validation activities, map the fluid flows within target formations, and create detailed thermal energy potential models to provide a basis for understanding the heat-use opportunities in the area. This knowledge can provide direction for future land use planning and development activities.

September 25, 2018

Geothermal Analysis

Big Lakes County

Study by Terrapin Geothermics

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

terrapin

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

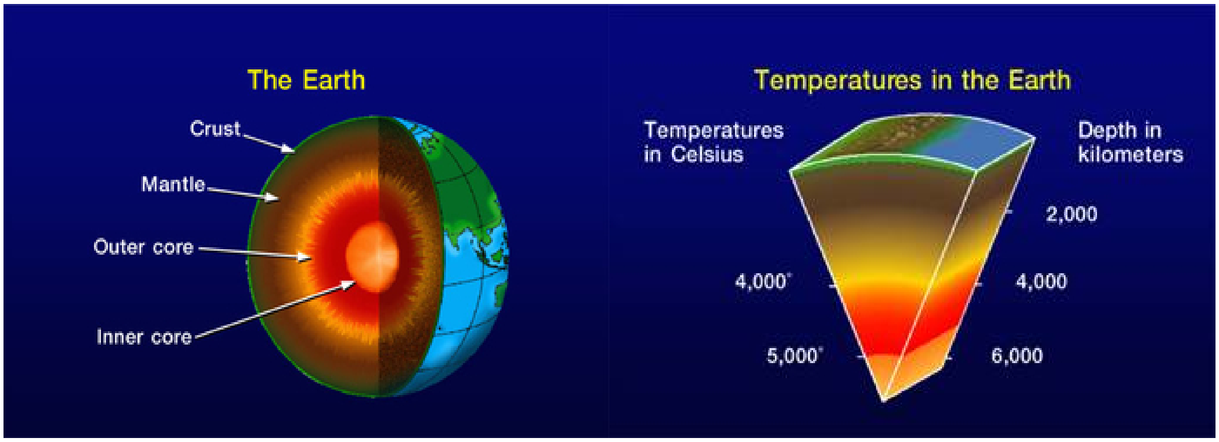
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

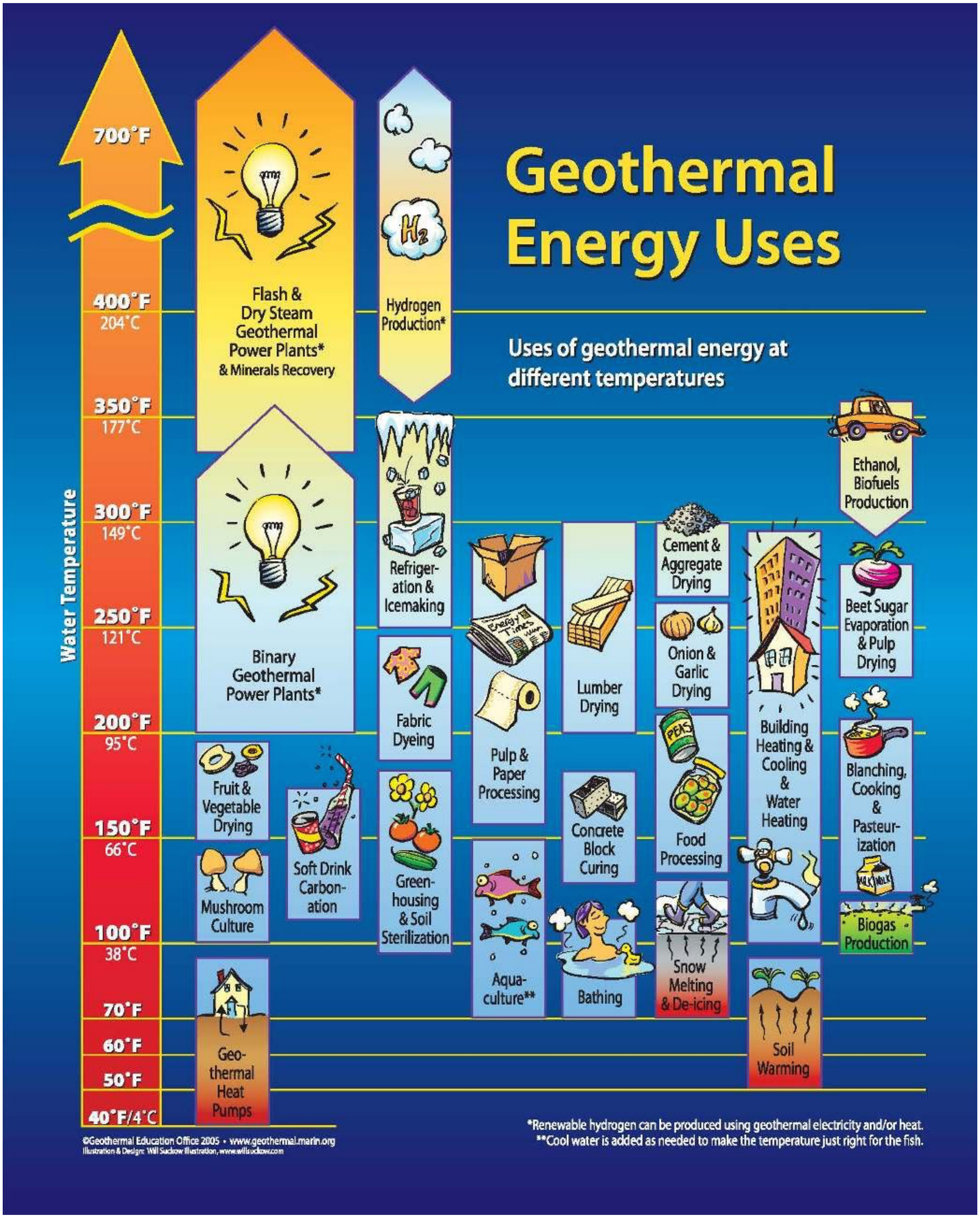
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160ºC and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180°C and above), medium (100-180°C), and low (80-100°C) temperature resources with fluids under 80°C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235°C or above); flash plants (turning geothermal fluids of at least 150°C into steam to drive a turbine); and binary power plants (using hot waters above 80°C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180°C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

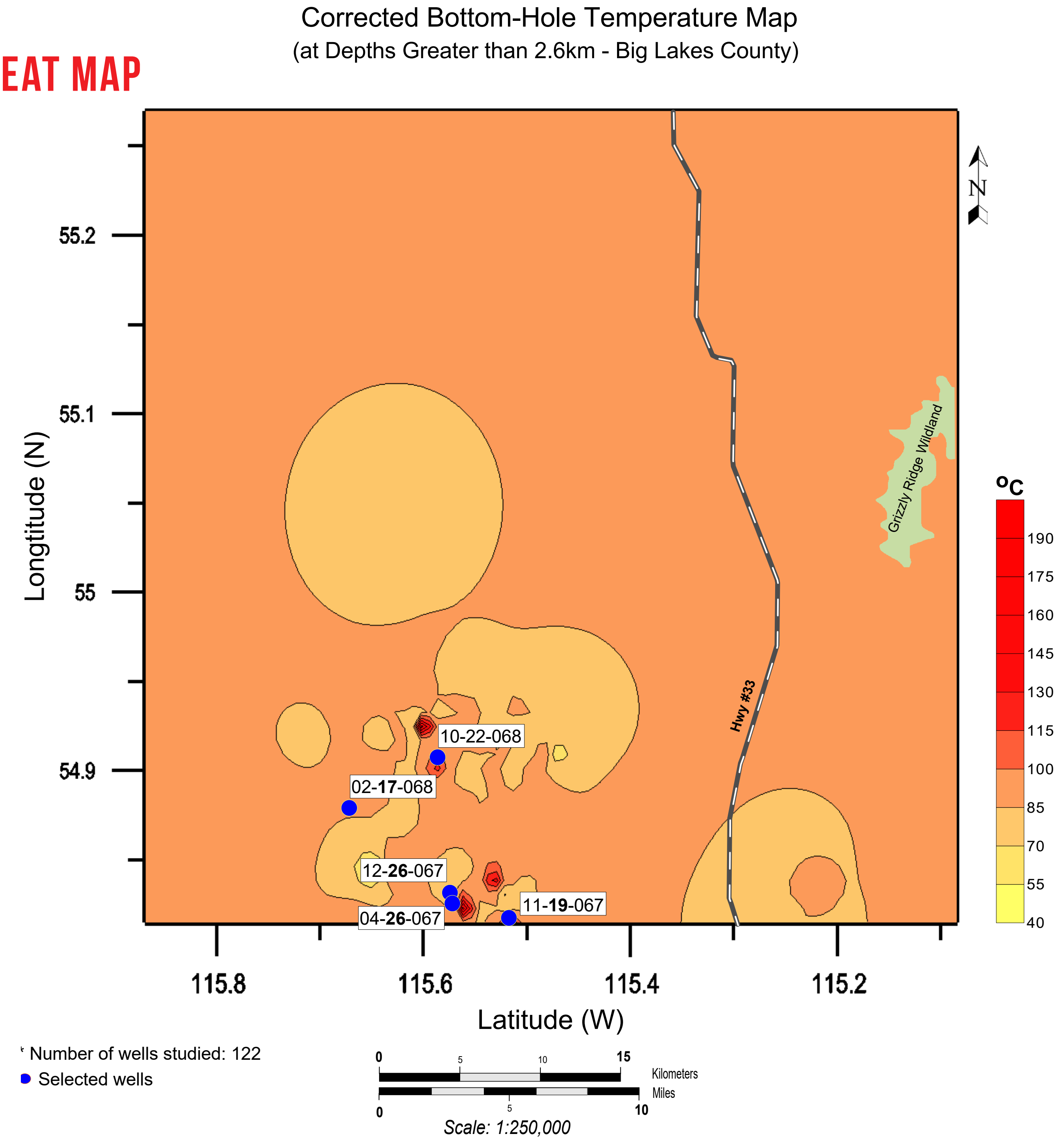
The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

RESEARCH RESULTS: BIG LAKES COUNTY

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

HEAT MAP

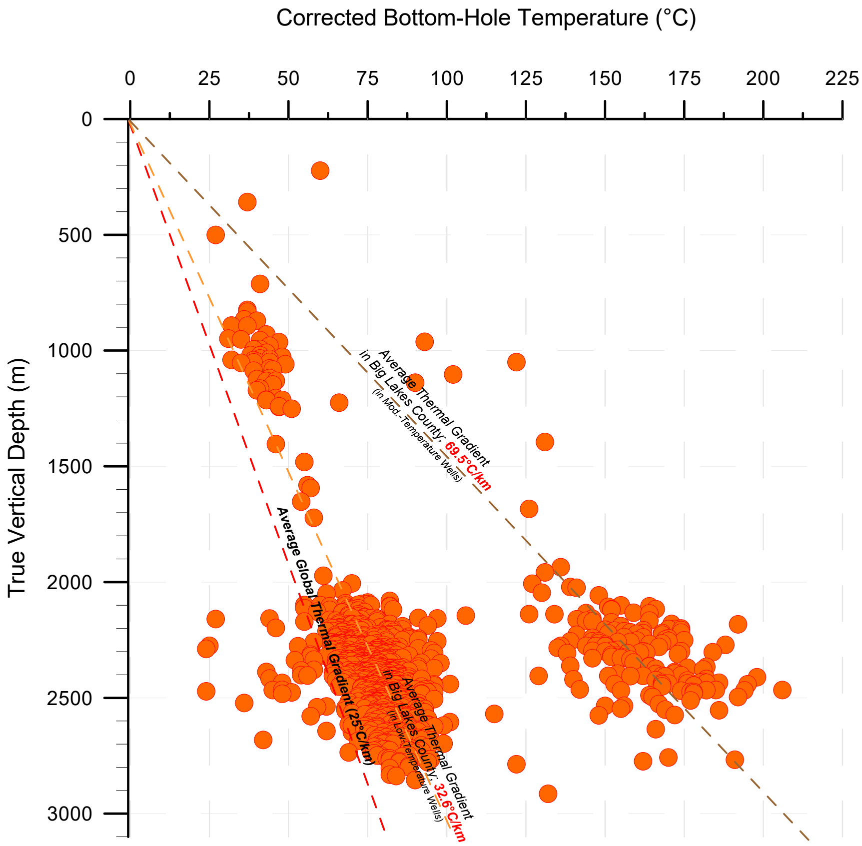


terrapin

RESEARCH RESULTS: BIG LAKES COUNTY

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 5 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation- Swan Hills F. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/11-19-067-10W5/00	2913.2	-414.6	132	140	Cdn Nat Rsrcs Ltd
100/02-17-068-11W5/00	2836.4	136.2	84	90	Penn West Cdn Fuel Ltd
100/12-26-067-11W5/00	2830.7	209.8	82	85	Crescent Point Enrg Corp
100/04-26-067-11W5/00	2802.5	159.3	82	85	Dark Enrg Ltd
100/10-22-068-11W5/00	2785.5	170.7	122	130	Acqstn Oil Corp

KEY TAKEAWAYS

- The geothermal formation underlying the study area is the **Swan Hills** formation.
- There are two collections of well temperatures providing above global average geothermal gradients in the study area: a low-temperature grouping providing a gradient of **32.6ºC/km** and a moderate temperature grouping providing a gradient of **69.5ºC/km**.
- The majority of wells drilled deeper than **2600m** are located in the south of the study area
- There is strong potential for **direct-use** applications and possible **power generation**

RECOMMENDATION & NOTES

Our research in Big Lakes County identified strong temperature readings across the study area with higher temperatures to the south. Our research also identified relatively thick (414m) geological formations underlying the study area which have the potential to contain large amounts of geothermal fluids. We recommend that the County undertake further studies that expand upon the geographic area of this initial scan. These studies include: temperature validation, mapping the fluid flows within target formations, and creating detailed thermal energy potential models. These studies will provide a basis for understanding the heat-use and power generation opportunities in the area and help direct future land use planning and development activities.

September 25, 2018

Geothermal Analysis

Birch Hills County

Study by Terrapin Geothermics

For further information,
contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

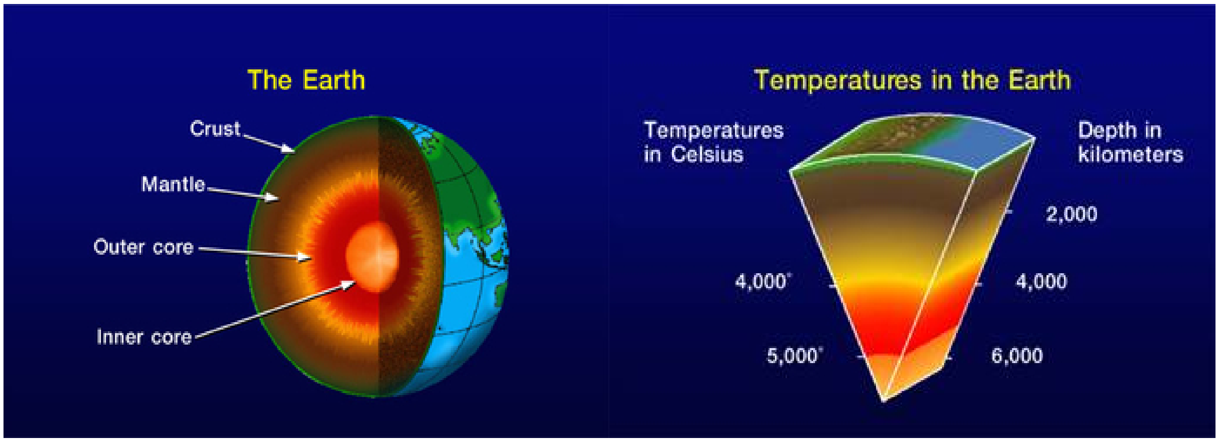
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

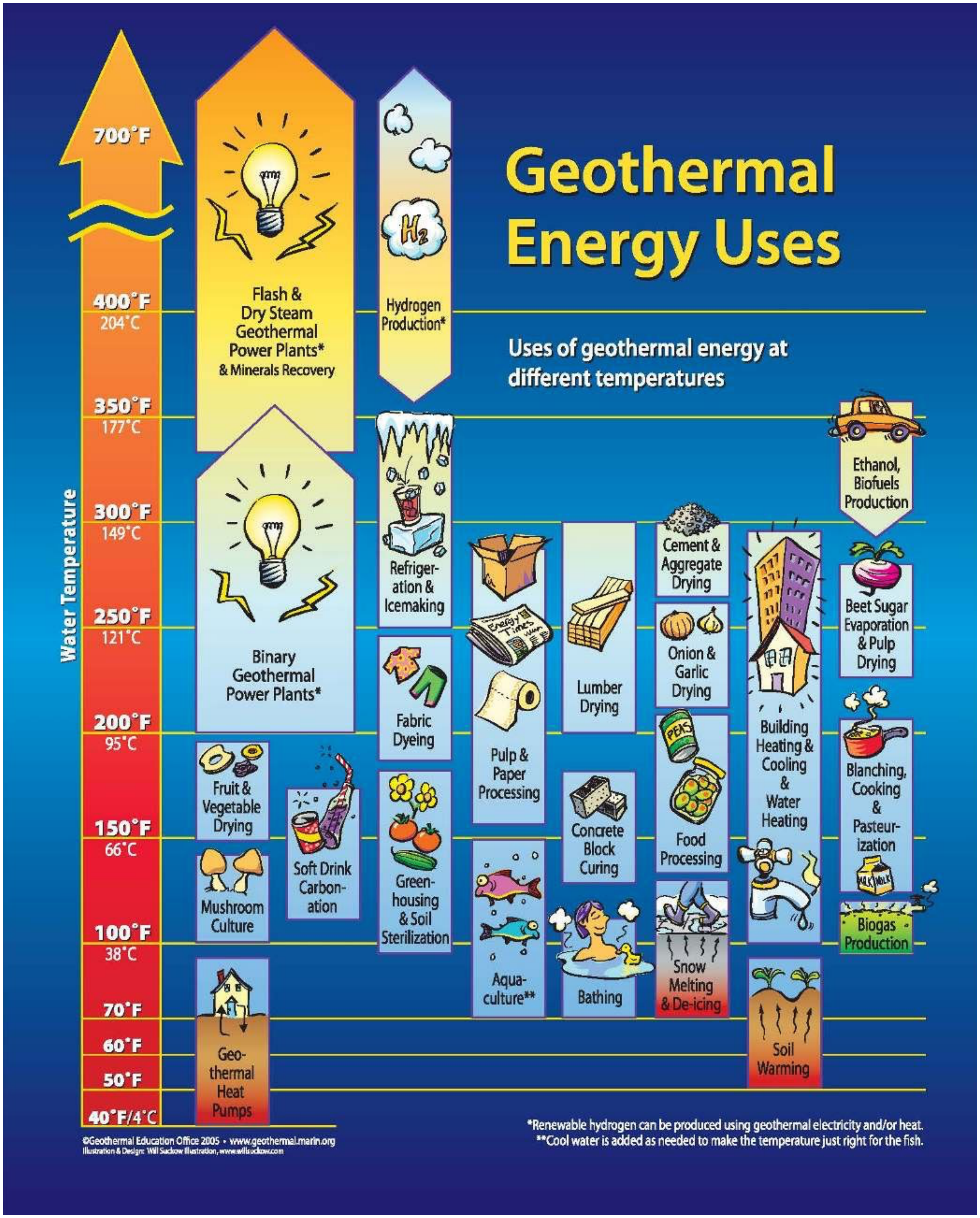
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160^{o}C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180ºC and above), medium (100-180ºC), and low (80-100ºC) temperature resources with fluids under 80ºC being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235ºC or above); flash plants (turning geothermal fluids of at least 150ºC into steam to drive a turbine); and binary power plants (using hot waters above 80ºC to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180ºC.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

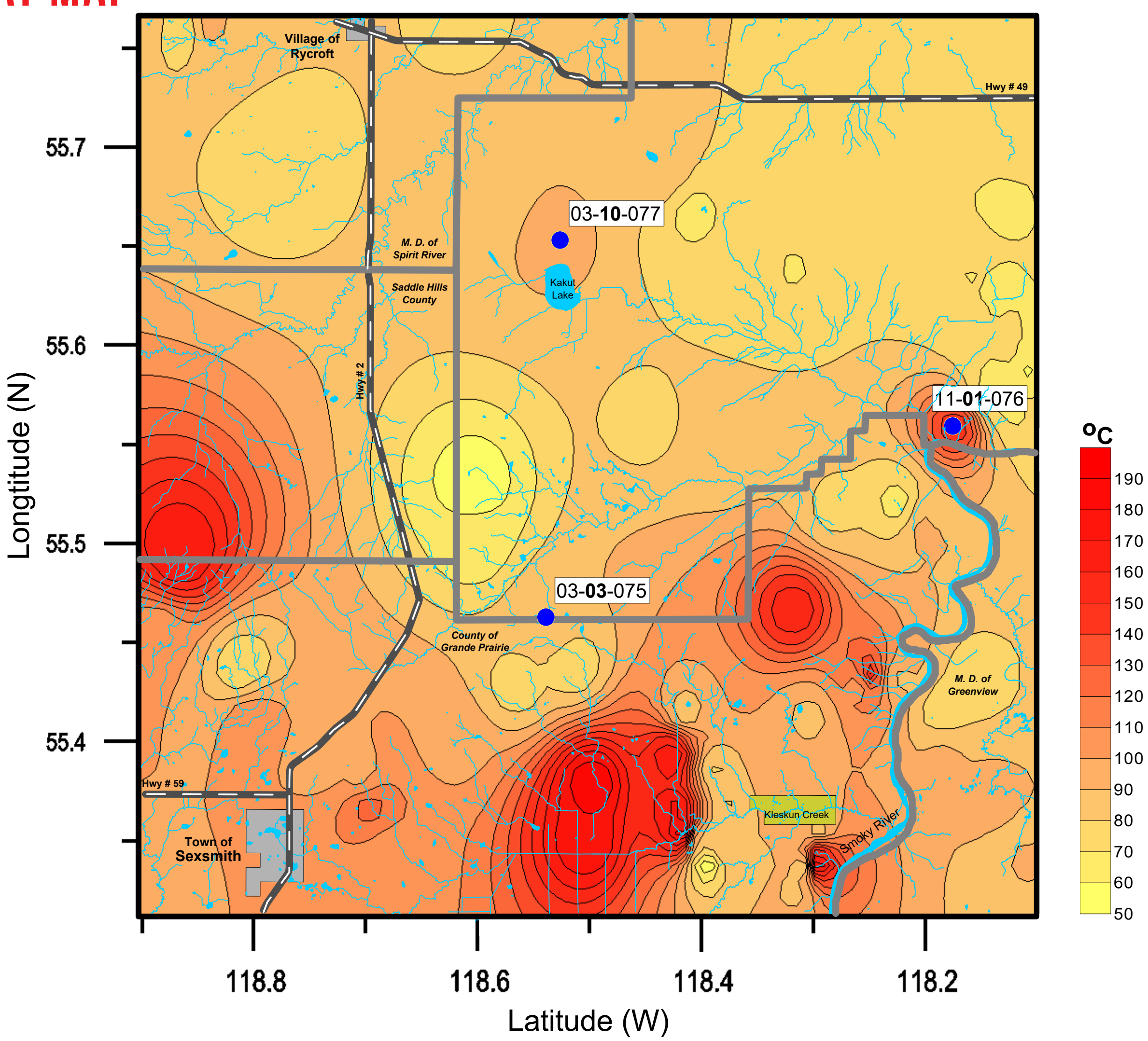
RESEARCH RESULTS: BIRCH HILLS COUNTY

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

Corrected Bottom-Hole Temperature Map
(at Depths Greater than 2.4km - Birch Hills County)

HEAT MAP



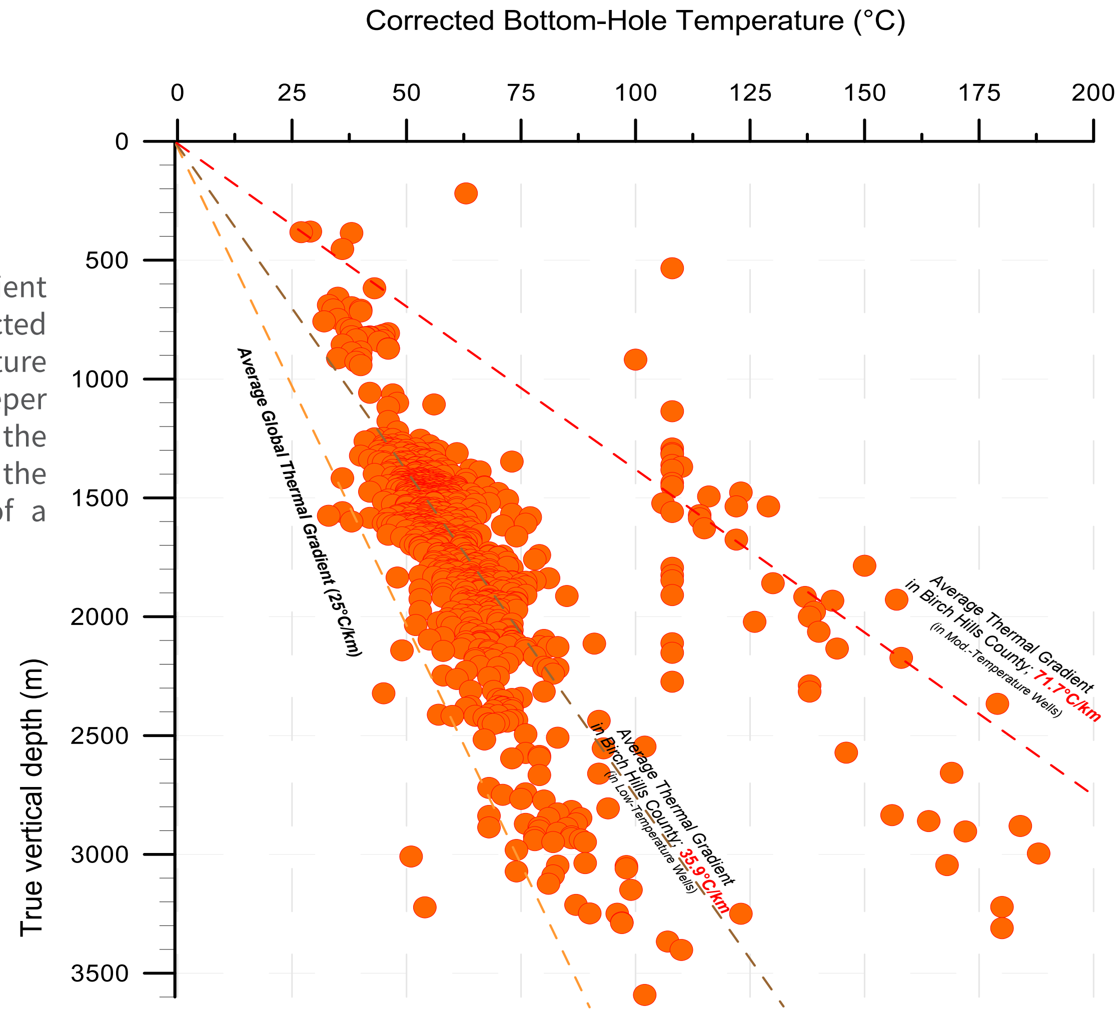
* Number of wells studied: 81
Selected wells

0 5 10 15 Kilometers
0 5 10 Miles
Scale: 1:250,000

RESEARCH RESULTS: BIRCH HILLS COUNTY

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 3 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Granite Wash F. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/11-01-076-02W6/00	2570.7	219.8	146	180	Hamilton Bros Cdn Gas
100/03-10-077-04W6/00	2552.4	239	93	120	Long Run Expl Ltd
100/03-03-075-04W6/00	3247	-459	90	100	Devon Cda Corp

KEY TAKEAWAYS

- The identified productive geothermal formation in your area is the **Granite Wash** formation
- There are two temperature data sets in the study area: a low-moderate set with an indicated gradient of **35.9ºC/km** and a moderate-high set with an indicated temperature gradient of **71.7ºC/km.** These are both significantly higher than the global average.
- There is potential for **geo-exchange** and possible **direct-use** activities in the study area

RECOMMENDATION & NOTES

Our investigation of Birch Hills County has uncovered a number of beneficial and potentially detrimental factors for geothermal development. There are consistently superior temperature readings that increase with well depth. However, though the Devonian strata has a moderate thickness (400m), the only identified productive geothermal formation in the study area is relatively thin (40m). Therefore, the productive formation may have the temperature to support sustained geothermal production but may not have the energy content. It is recommended that the County conduct temperature verification and reservoir modelling activities to investigate the energy potential of the identified geothermal formation.

September 25, 2018

Geothermal Analysis

Cold Lake

Study by Terrapin Geothermics

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

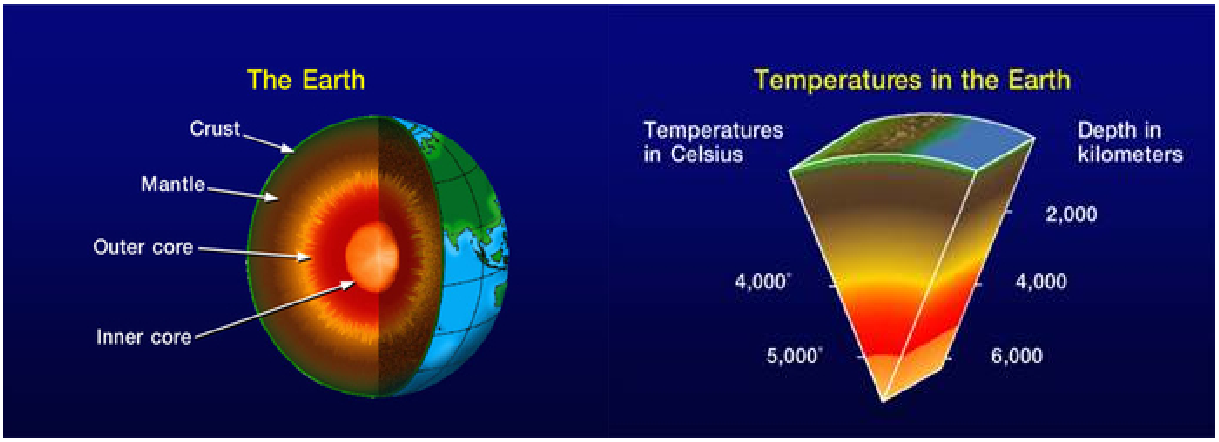
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

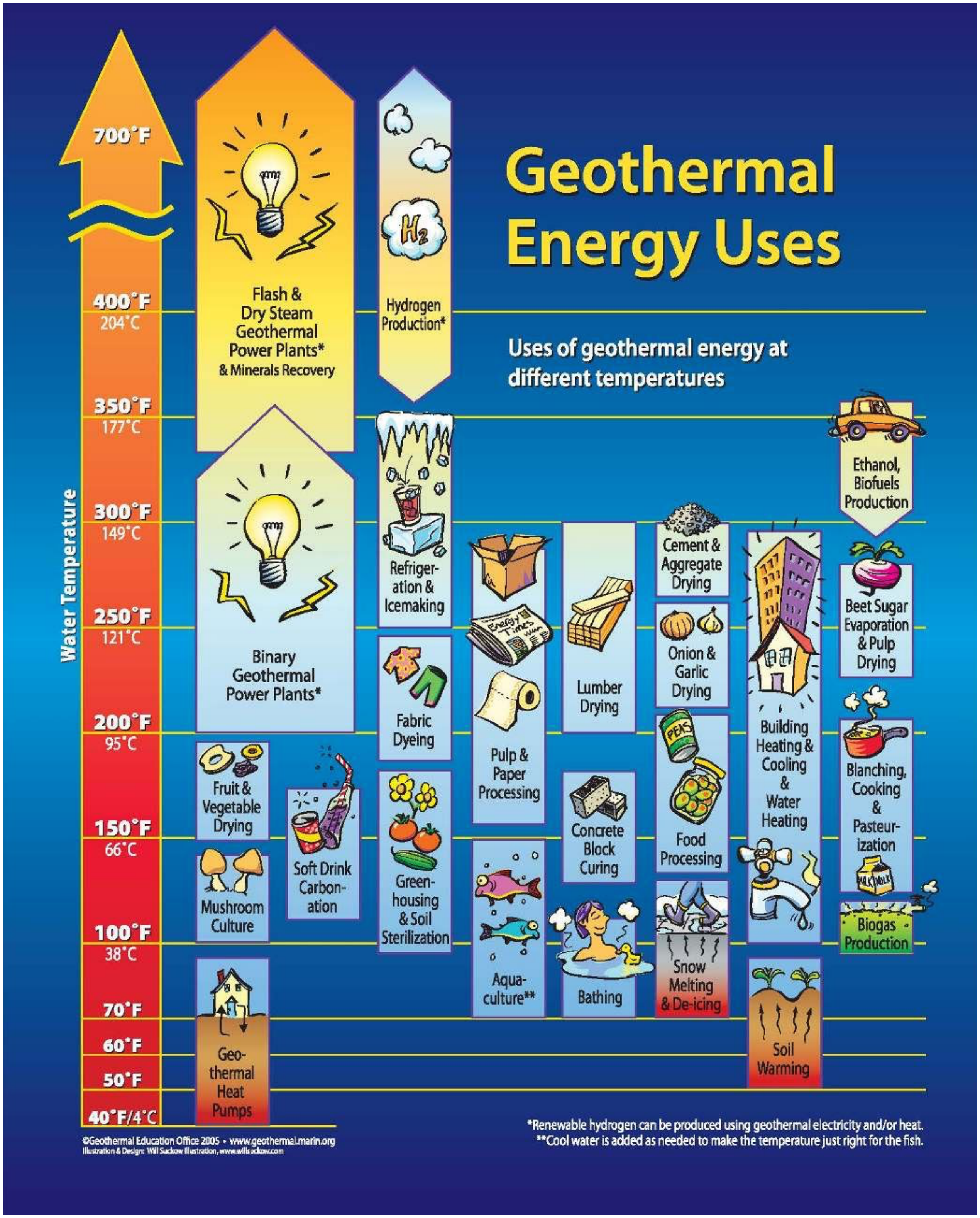
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000°C, for comparison, the temperature on the surface of the sun is approximately 5,500°C. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth’s surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton’s Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160^{o}C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180°C and above), medium (100-180°C), and low (80-100°C) temperature resources with fluids under 80°C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235°C or above); flash plants (turning geothermal fluids of at least 150°C into steam to drive a turbine); and binary power plants (using hot waters above 80°C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180°C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

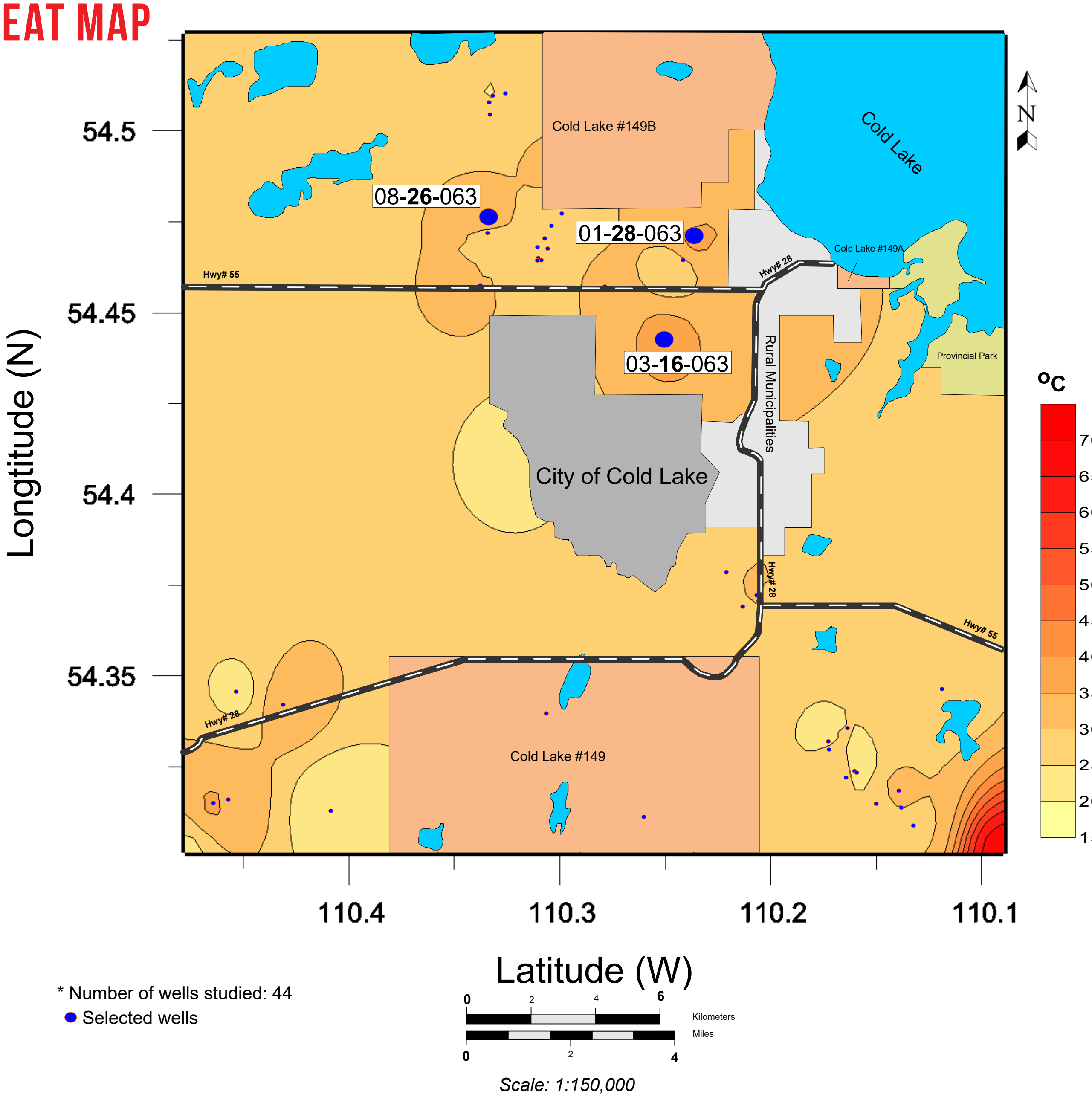
RESEARCH RESULTS: COLD LAKE

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

HEAT MAP

Corrected Bottom-Hole Temperature Map
(at Depths Greater than 0.6km - City of Cold Lake)

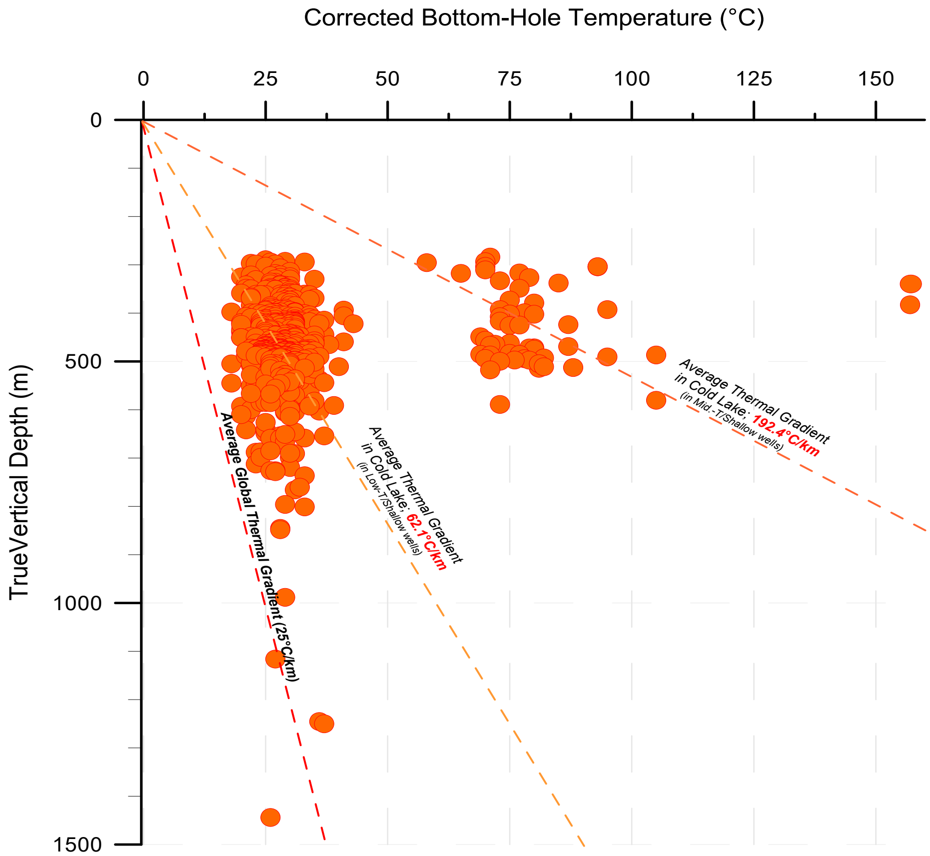


* Number of wells studied: 44
● Selected wells

RESEARCH RESULTS: COLD LAKE

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 3 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Watt Mnt. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/01-28-063-02W4/00	1249.6	-650.4	37	45	High-Level Enrg Ltd
102/08-26-063-03W4/00	1244.9	-645.7	36	45	Cnsld Beacon Rsrcs Ltd
100/03-16-063-02W4/00	653.6	-54.4	37	45	Cdn Nat Rsrcs Ltd

KEY TAKEAWAYS

- There are two potential geothermal formations in your area: **Watt Mountain** and **Granite Wash**. Watt Mountain is shallow, occurring at 590m depth, and extremely thin, 5-16m. The Granite Wash is also shallow, occurring at 1156m and 75m thick.
- There are two sets of temperature data in the study area with indicated thermal gradients of **62.1** and **192.4ºC/km**.
- There is potential for **geo-exchange** in the study area and temperature readings high enough for direct-use.

RECOMMENDATION & NOTES

Our study of Cold Lake has uncovered factors that are detrimental to large-scale geothermal development in the area. The only geothermal formations in the study area are shallow and do not have the temperatures to support direct use activities. As well, the majority of wells in the region are also shallow with temperature readings coming from less than 750m deep. This lack of drilled depth compounds potentially anomalous temperature readings, improper measurement gathering, and data entry errors, leading to a severe overestimation of the temperature potential. It is recommended that the City validate the cluster of high temperature readings for possible direct-use opportunities and also investigate the opportunity to build geo-exchange systems to take advantage of the relatively stable temperature below the frostline.

September 25, 2018

Geothermal Analysis

Grande Prairie

Study by Terrapin Geothermics

For further information,
contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

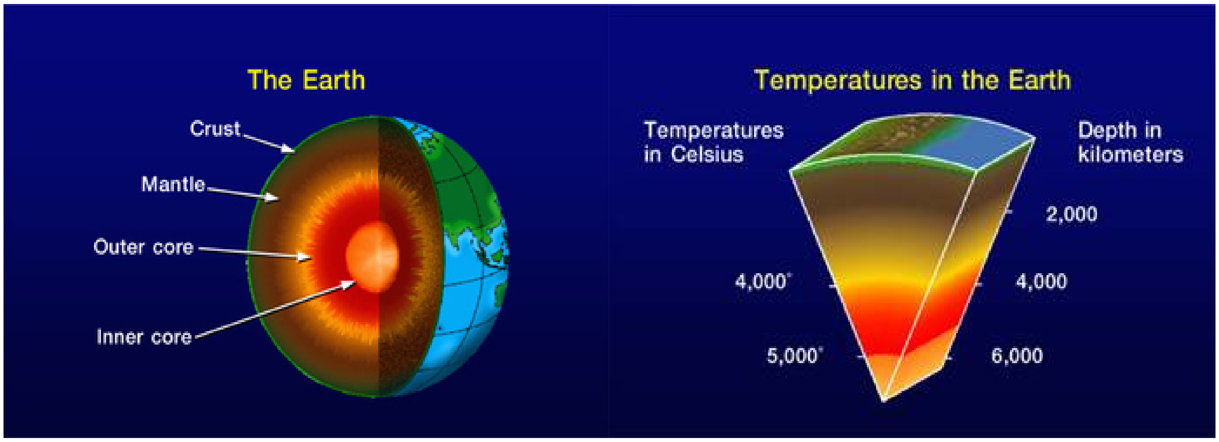
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

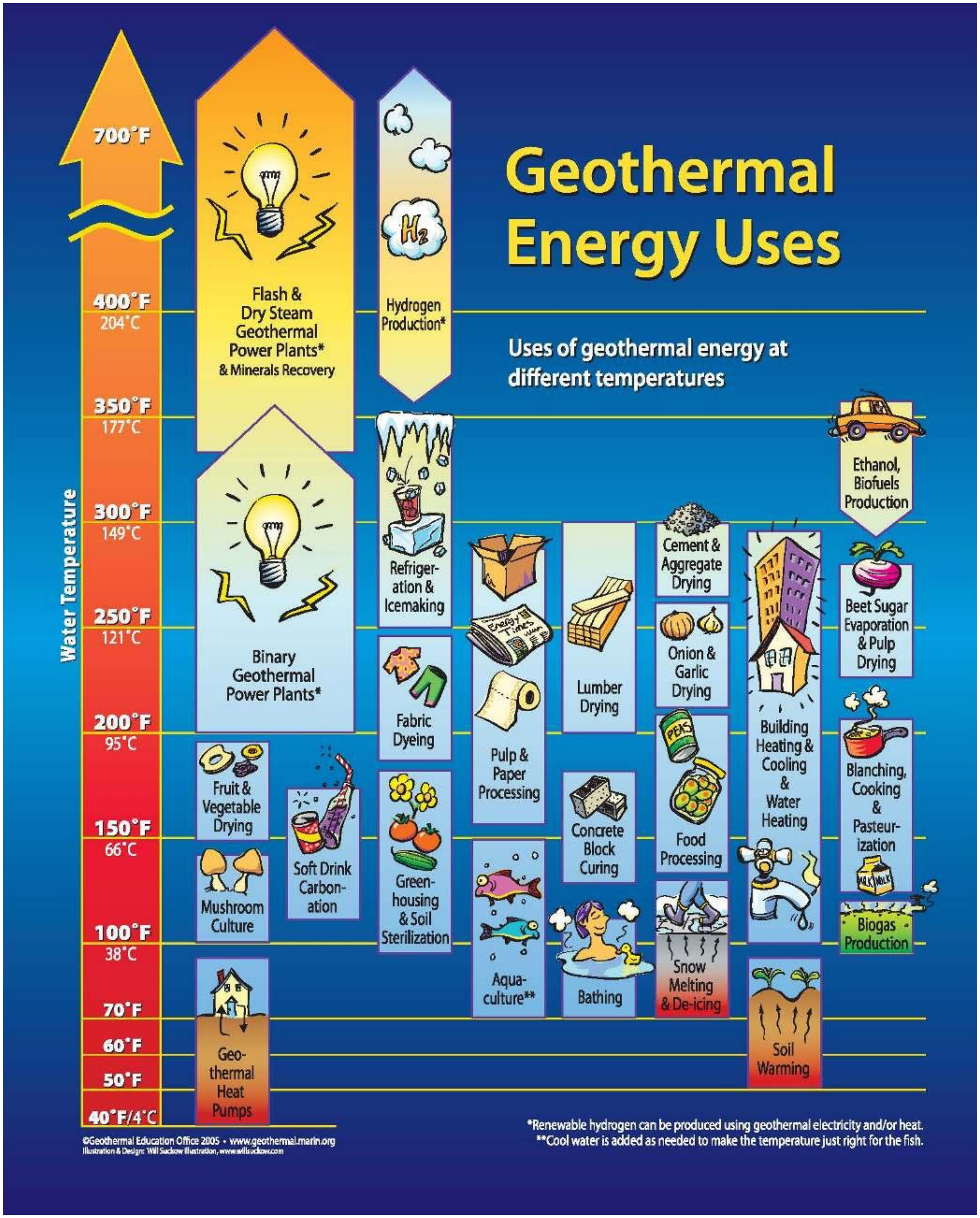
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

“Direct use” refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland’s homes and the district heating utility in Reykjavik serves approximately 60% of Iceland’s population.[1] A further example of direct use is the 5,000-acre Oserian Development Company’s flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160^{o}C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., “85 Years of Successful District Heating in Reykjavík, Iceland”, *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180^{o}C and above), medium (100-180^{o}C), and low (80-100^{o}C) temperature resources with fluids under 80^{o}C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235^{o}C or above); flash plants (turning geothermal fluids of at least 150^{o}C into steam to drive a turbine); and binary power plants (using hot waters above 80^{o}C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180^{o}C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

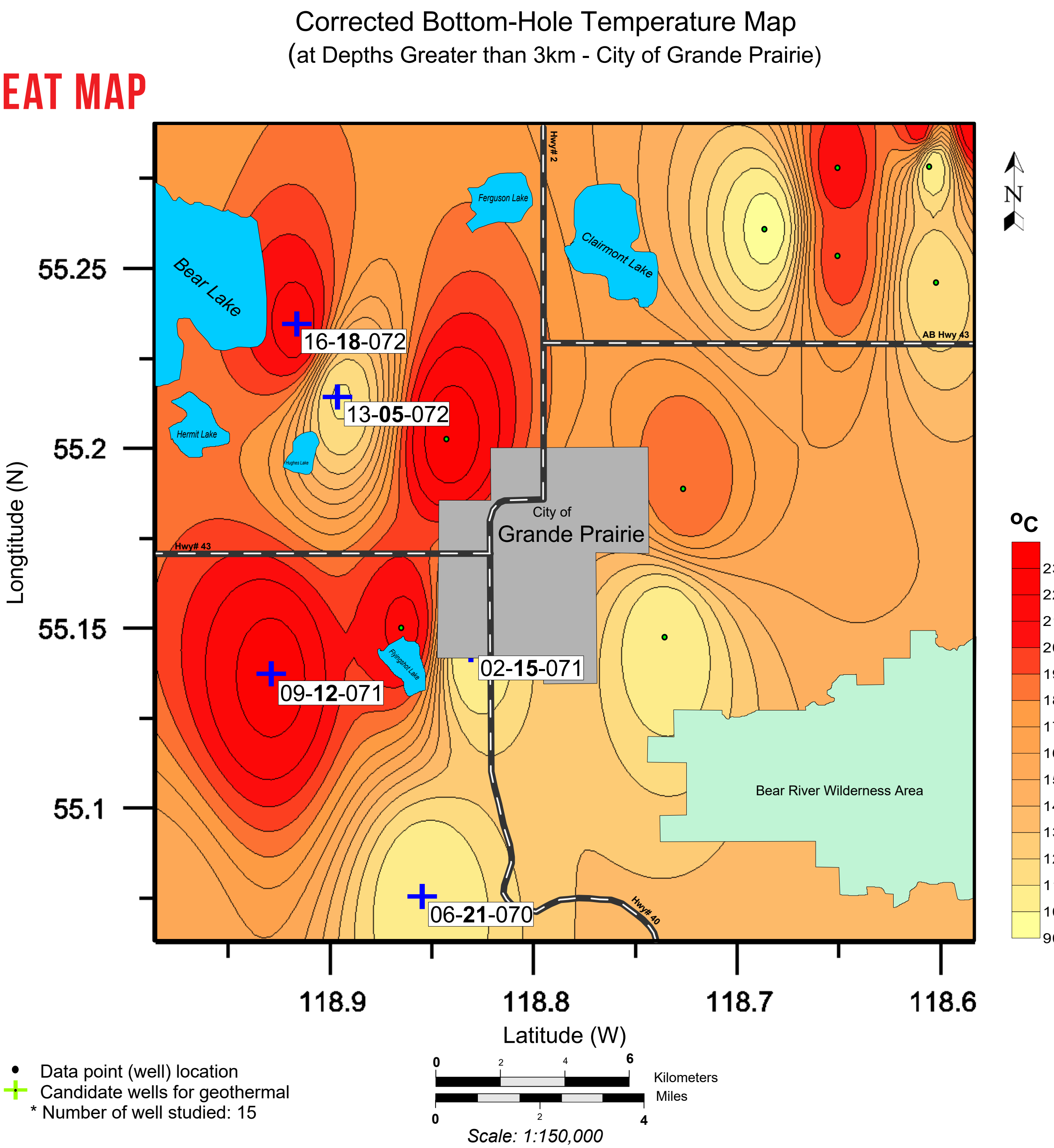
The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

RESEARCH RESULTS: GRANDE PRAIRIE

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

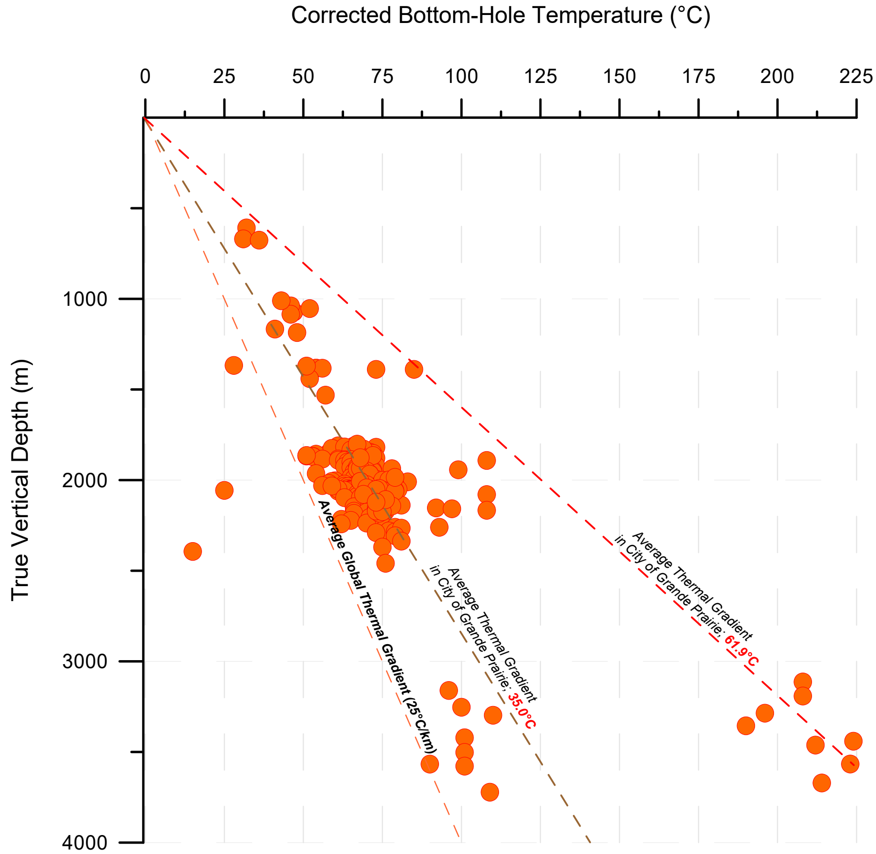
HEAT MAP



RESEARCH RESULTS: GRANDE PRAIRIE

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 5 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Leduc (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/02-15-071-06W6/00	3501.2	-257.5	101	120	Shell Cda Ltd
100/09-12-071-07W6/00	3565.2	-321.5	223	225	Chevron Cda Prop Lmtd
100/06-21-070-06W6/00	3576.9	-333.2	101	120	Cdn Nat Rsrcs Ltd
100/06-18-072-06W6/00	3669.7	-426	214	225	ConocoPhillips Cda Rsrcs
100/13-05-072-06W6/00	3720.5	-476.8	109	120	Flow-Back O&G Ltd

KEY TAKEAWAYS

- The Ideal geothermally productive formation in your area is the **Leduc formation**.
- There are two temperature data sets in the study area. The low-moderate data set indicates a temperature gradient of **35°C/km** and the moderate-high data set shows a gradient of **61.9°C/km**.
- **Direct-use** opportunities exist throughout the study are and the potential for **power generation** activities may exist to the west of Grande Prairie.

RECOMMENDATION & NOTES

Our research work around Grande Prairie identified the potential opportunity for direct-use and/or power generation activities. We have identified two distinct data sets related to Bottom Hole Temperature measurements: a low-moderate grouping and a moderate-high temperature grouping. A number of temperatures recorded to the west of the city are among the highest readings that our geology team has seen in Alberta. It is very strongly recommended that Grande Prairie pursue further research to investigate both of these opportunities. Specific studies should seek to validate this initial temperature data, map fluid flows within target formations, and create detailed energy potential models to assess the magnitude and viability of this seemingly large opportunity.

September 25, 2018

Geothermal Analysis

Clear Hills County

Study by Terrapin Geothermics

For further information,
contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

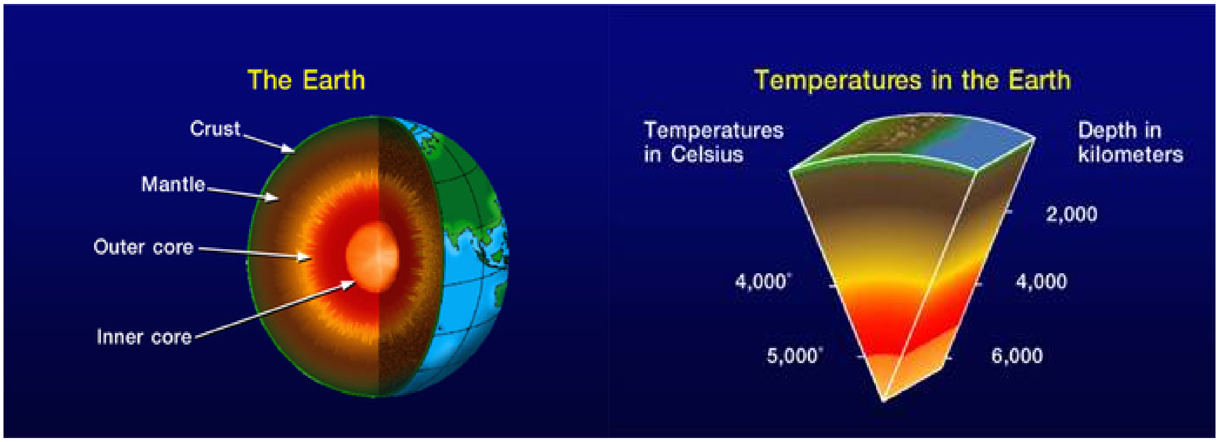
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

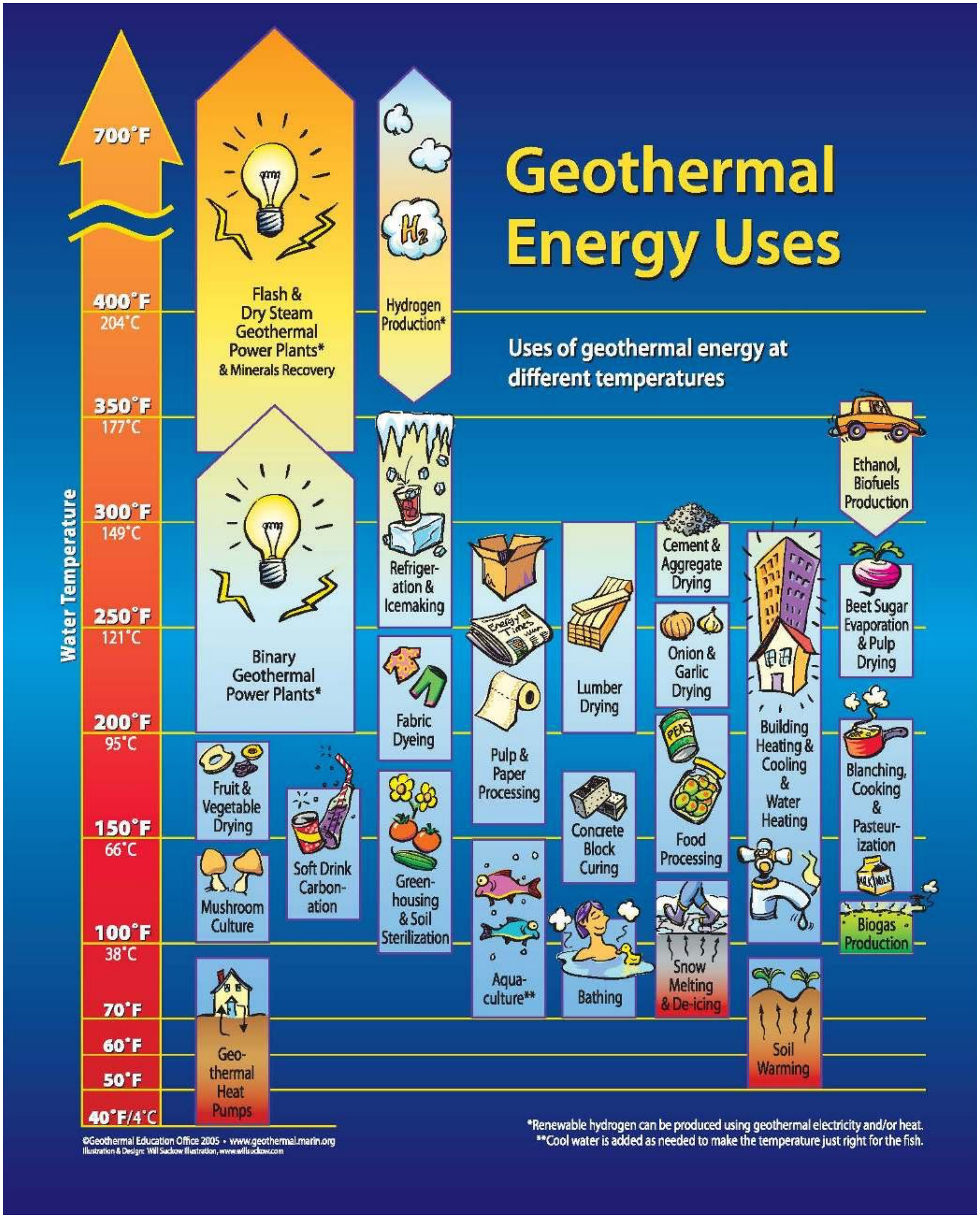
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth’s surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton’s Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180°C and above), medium (100-180°C), and low (80-100°C) temperature resources with fluids under 80°C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235°C or above); flash plants (turning geothermal fluids of at least 150°C into steam to drive a turbine); and binary power plants (using hot waters above 80°C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180°C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

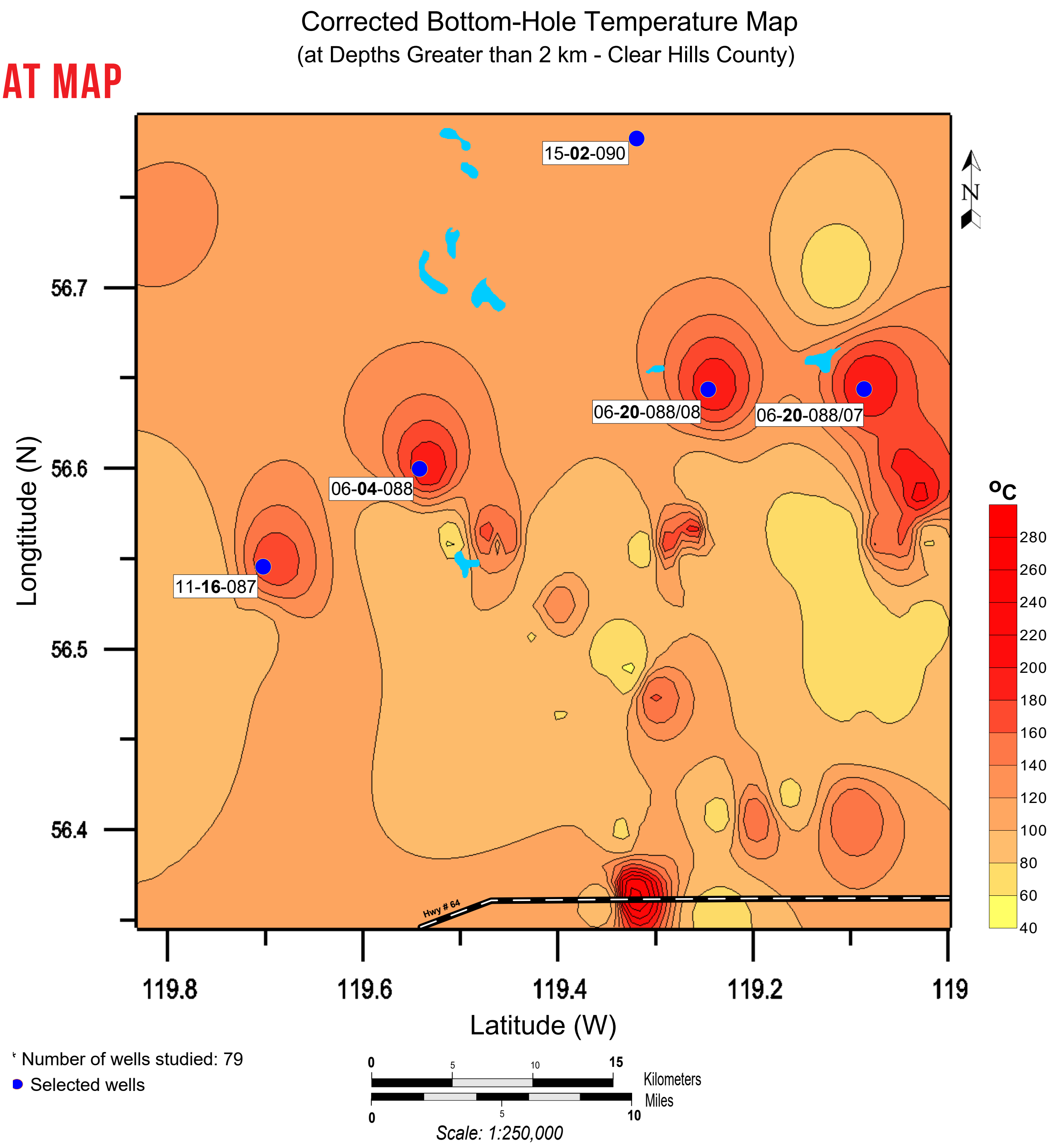
The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

RESEARCH RESULTS: CLEAR HILLS COUNTY

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

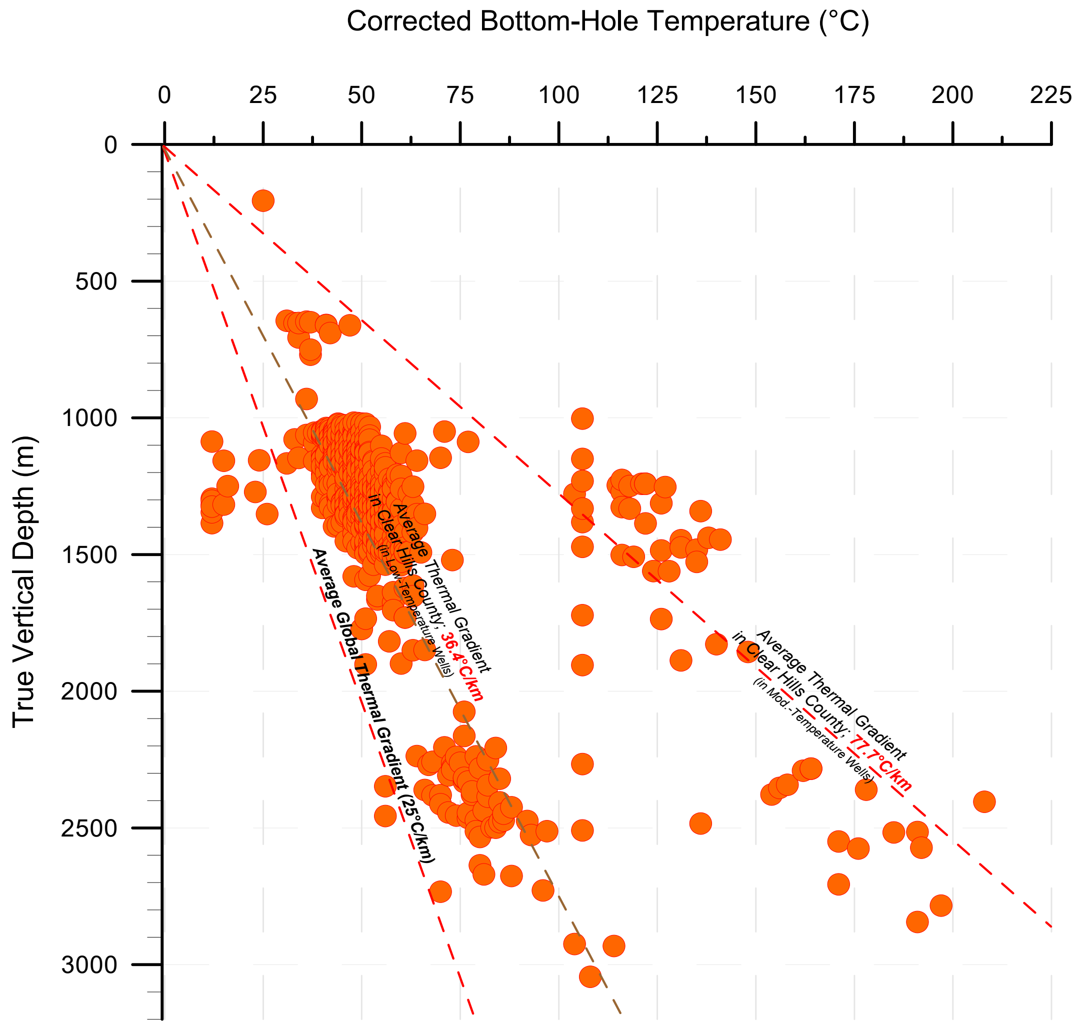
HEAT MAP



RESEARCH RESULTS: CLEAR HILLS COUNTY

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 5 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Granite Wash F. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/15-02-090-09W6/00	2930.8	-100	114	120	Chevron Cda Ltd
100/06-20-088-08W6/00	2843	-82.6	191	205	Shell Cda Ltd
100/06-20-088-07W6/00	2783.1	-89.3	197	210	Shoreline Enrg Corp
100/11-16-087-11W6/00	2705.4	-193	171	190	BP Cda Enrg Grp ULC
100/06-04-088-10W6/00	2571.3	-61.6	192	220	Imperial Oil Rsrcs Ltd(2)

KEY TAKEAWAYS

- The identified geothermally productive formations in the study area are the **Granite Wash** and **Leduc** formations.
- There are two temperature data sets in the study area. The low-moderate data set indicates a gradient of **36.4ºC/km** and the moderate-high data set shows a gradient of **77.7ºC/km**.
- There is strong potential for **power generation** activities in the county

RECOMMENDATION & NOTES

Our research in Clear Hills County has identified two distinct temperature data sets: a low-moderate grouping and a moderate-high temperature grouping. The moderate-high grouping is amongst the strongest geothermal potential that our geology team has discovered in Alberta and the linear pattern in the distribution of hotter wells is indicative of possible geological structures and/or anomalies in the area at a depth greater than 2km. It is very strongly recommended that Clear Hills County pursue further research in this area. Specific studies should expand the scope of work to the entire county, seek to validate this initial temperature and geological data, map fluid flows within target formations and create detailed energy potential models to assess the magnitude and viability of this seemingly large opportunity.

September 25, 2018

Geothermal Analysis

County of Northern Lights

Study by Terrapin Geothermics

For further information,
contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

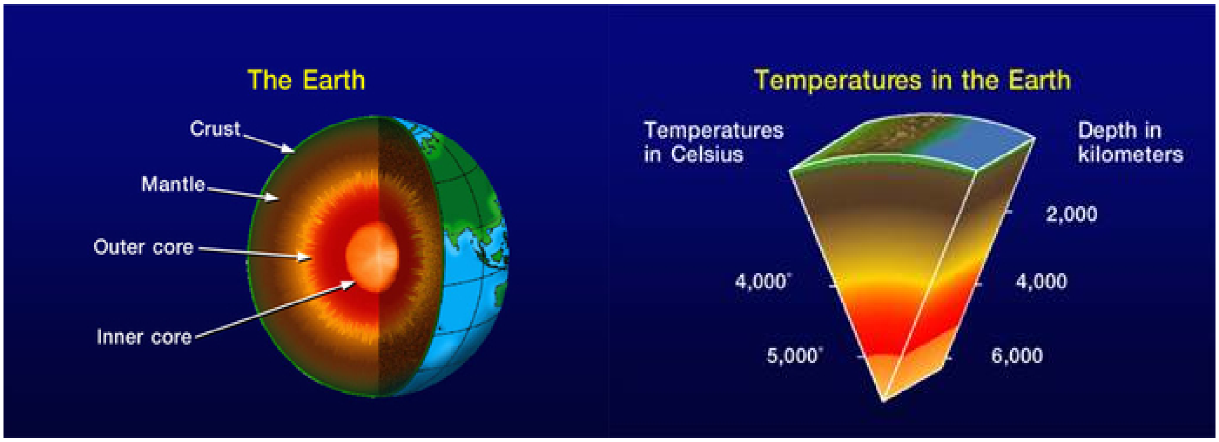
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

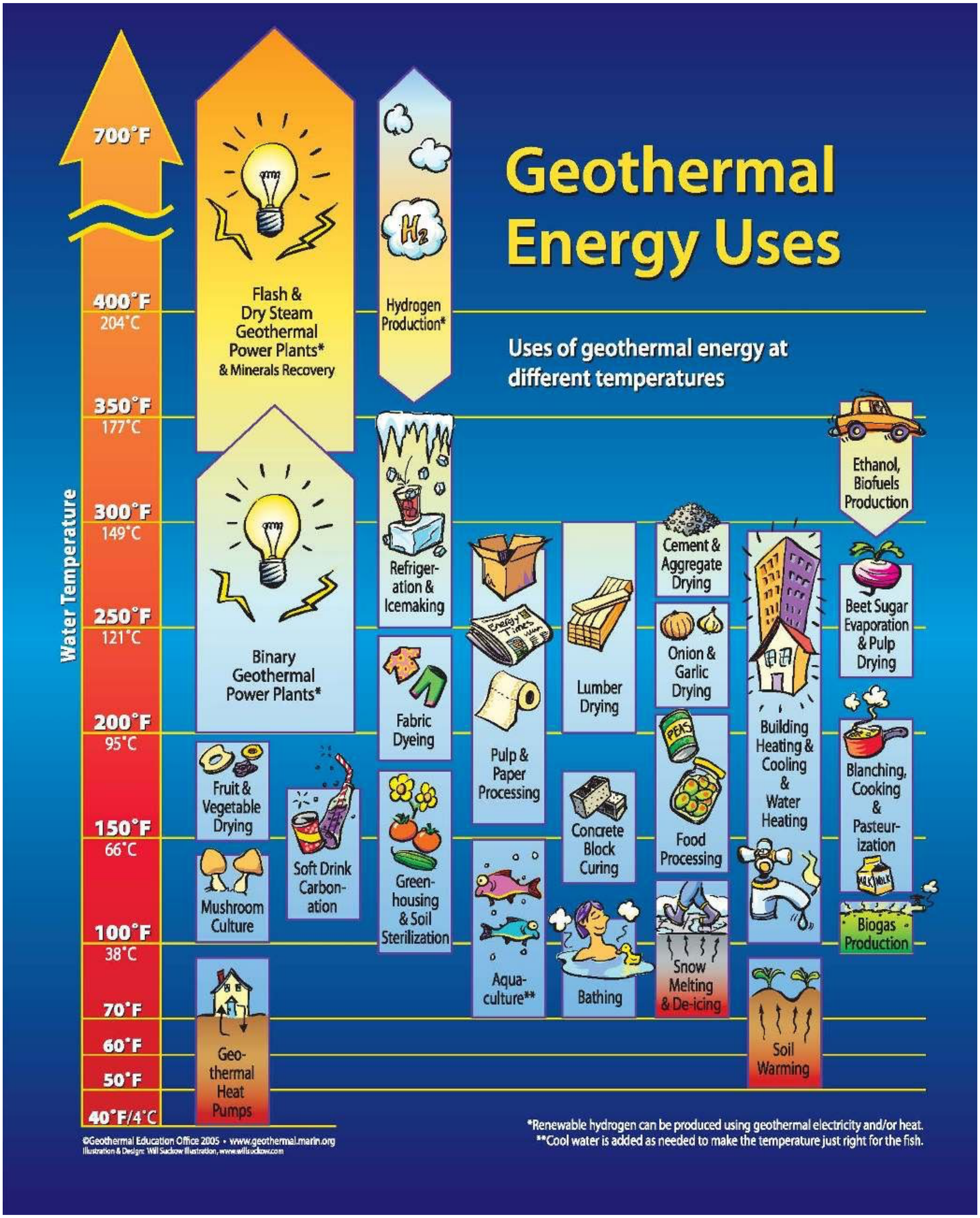
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180^{o}C and above), medium (100-180^{o}C), and low (80-100^{o}C) temperature resources with fluids under 80^{o}C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235^{o}C or above); flash plants (turning geothermal fluids of at least 150^{o}C into steam to drive a turbine); and binary power plants (using hot waters above 80^{o}C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180^{o}C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

RESEARCH RESULTS:
COUNTY OF NORTHERN LIGHTS

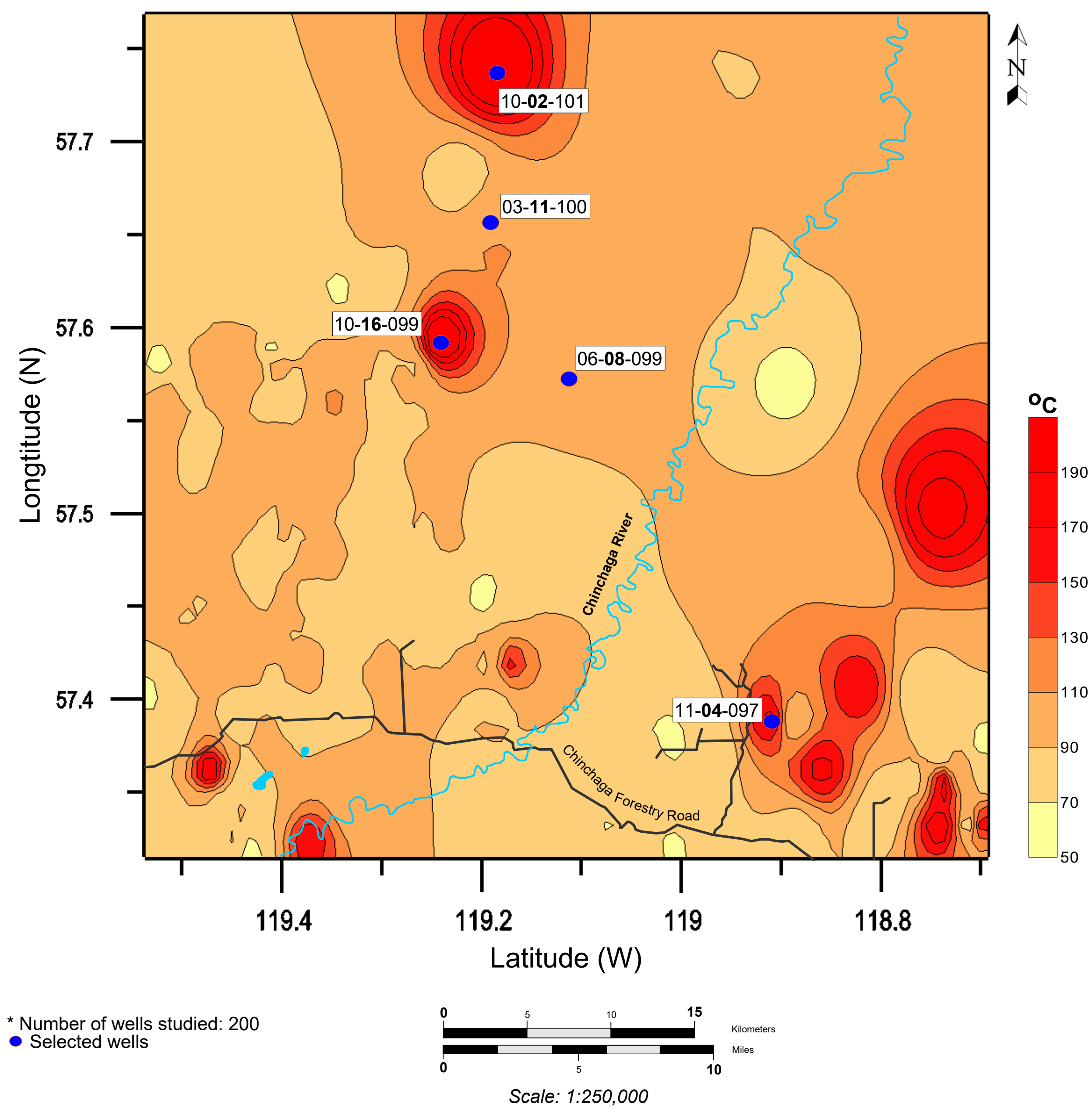
terrapin

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

HEAT MAP

Corrected Bottom-Hole Temperature Map
(at Depths Greater than 2.3km - County of Northern Lights)

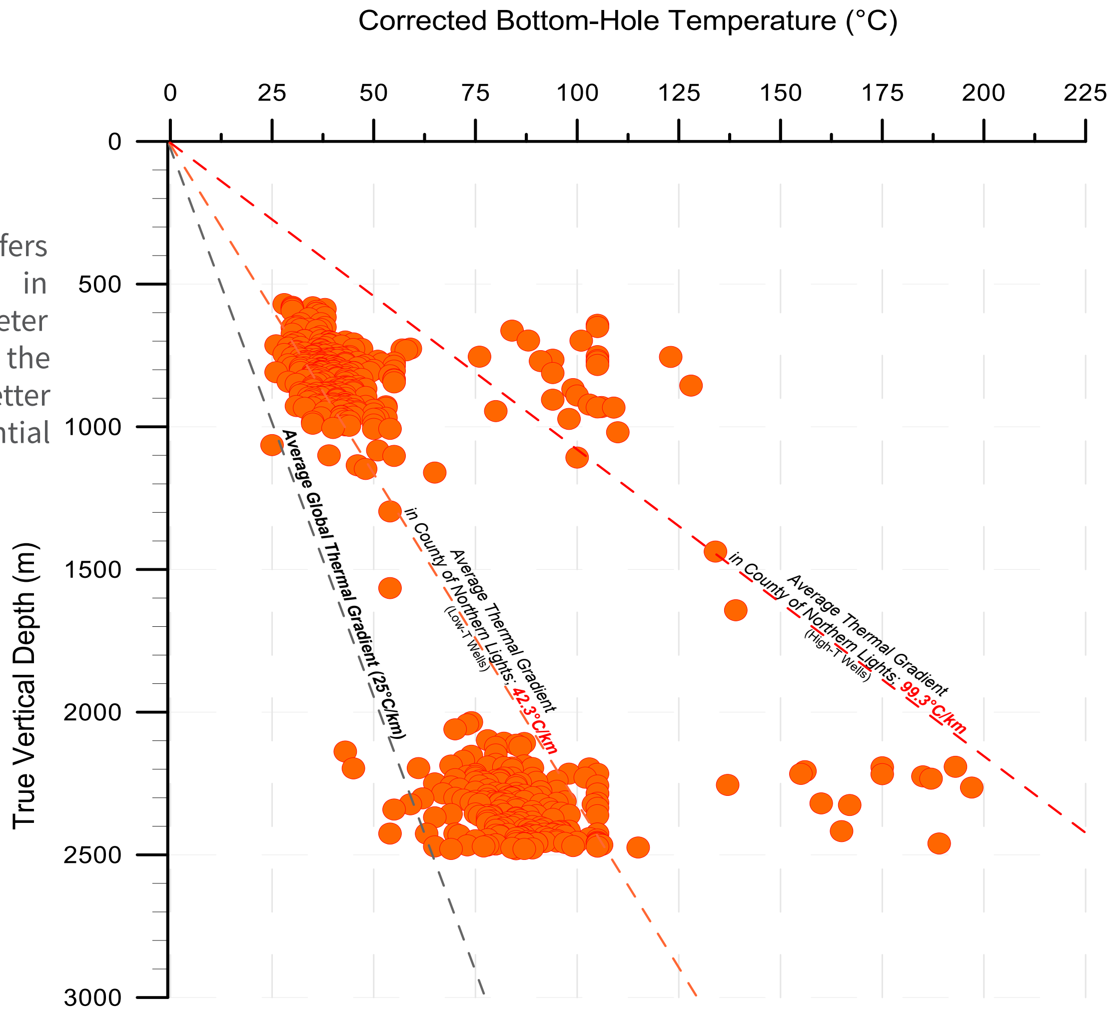


RESEARCH RESULTS:

COUNTY OF NORTHERN LIGHTS

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 5 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Gilwood Member (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/10-16-099-08W6/02	2726.4	-426.4	225	230	Cdn Nat Rsrcs Ltd
100/11-04-097-06W6/00	2720.9	-420.9	174	180	Nyrstar Myra Falls Ltd
100/06-08-099-07W6/00	2651.4	-351.4	104	120	Plains Midstream Cda ULC
100/03-11-100-08W6/00	2643.9	-343.9	103	120	Polar Star Cdn O&G Inc
100/10-02-101-08W6/00	2635	-335	220	230	Imperial Oil Ltd

KEY TAKEAWAYS

- The identified productive geothermal formation in your area is the **Gilwood** member
- There are two sets of temperature readings in the study area: the low-moderate grouping indicates a gradient of **42.3ºC/km and the moderate-high grouping indicates a gradient of 99.3ºC/km.**
- There is potential for **direct-use** and/or **power generation** activities in the study area

RECOMMENDATION & NOTES

Our investigation of the County of Northern Lights has uncovered an excellent overall gradient within the study area. There are consistently superior temperature readings that increase with well depth. However, the only identified productive geothermal formation, the Gilwood, is quite thin (5-10m) in the area and may not contain enough fluid to support geothermal production. We recommend that the County undertake a further study which validates the identified temperatures and expands the scope of the work to encompass the entire County in order to find thicker, fluid-bearing formations. This knowledge can provide direction for future land use planning and development activities.

September 25, 2018

Geothermal Analysis

County of St. Paul

Study by Terrapin Geothermics

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.

Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.

More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

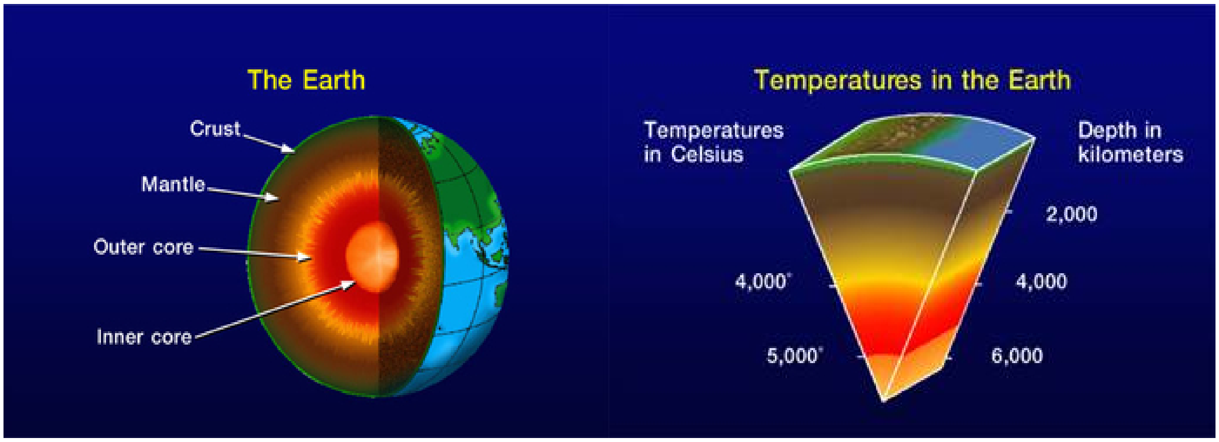
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

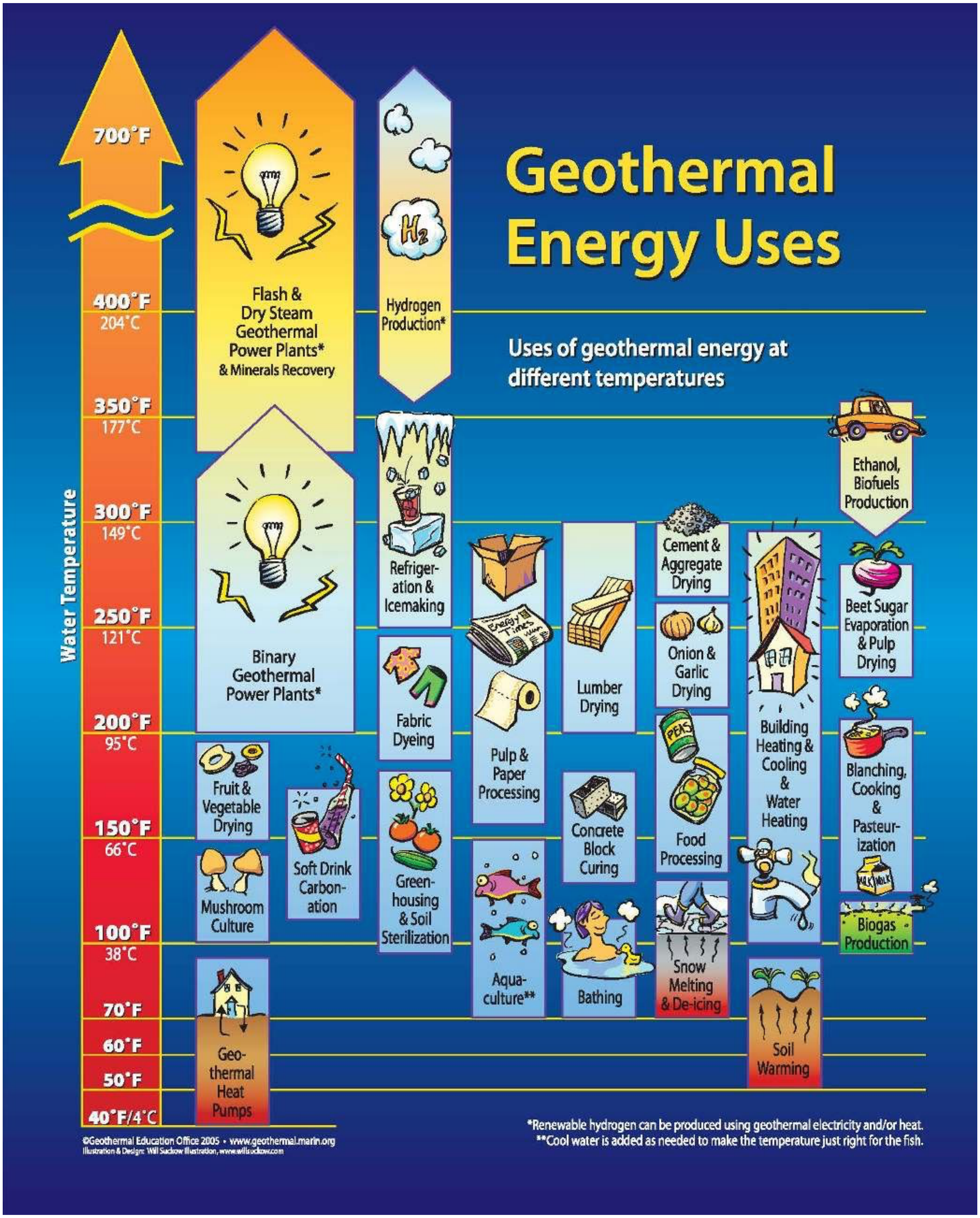
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160ºC and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180^{o}C and above), medium (100-180^{o}C), and low (80-100^{o}C) temperature resources with fluids under 80^{o}C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235^{o}C or above); flash plants (turning geothermal fluids of at least 150^{o}C into steam to drive a turbine); and binary power plants (using hot waters above 80^{o}C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180^{o}C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

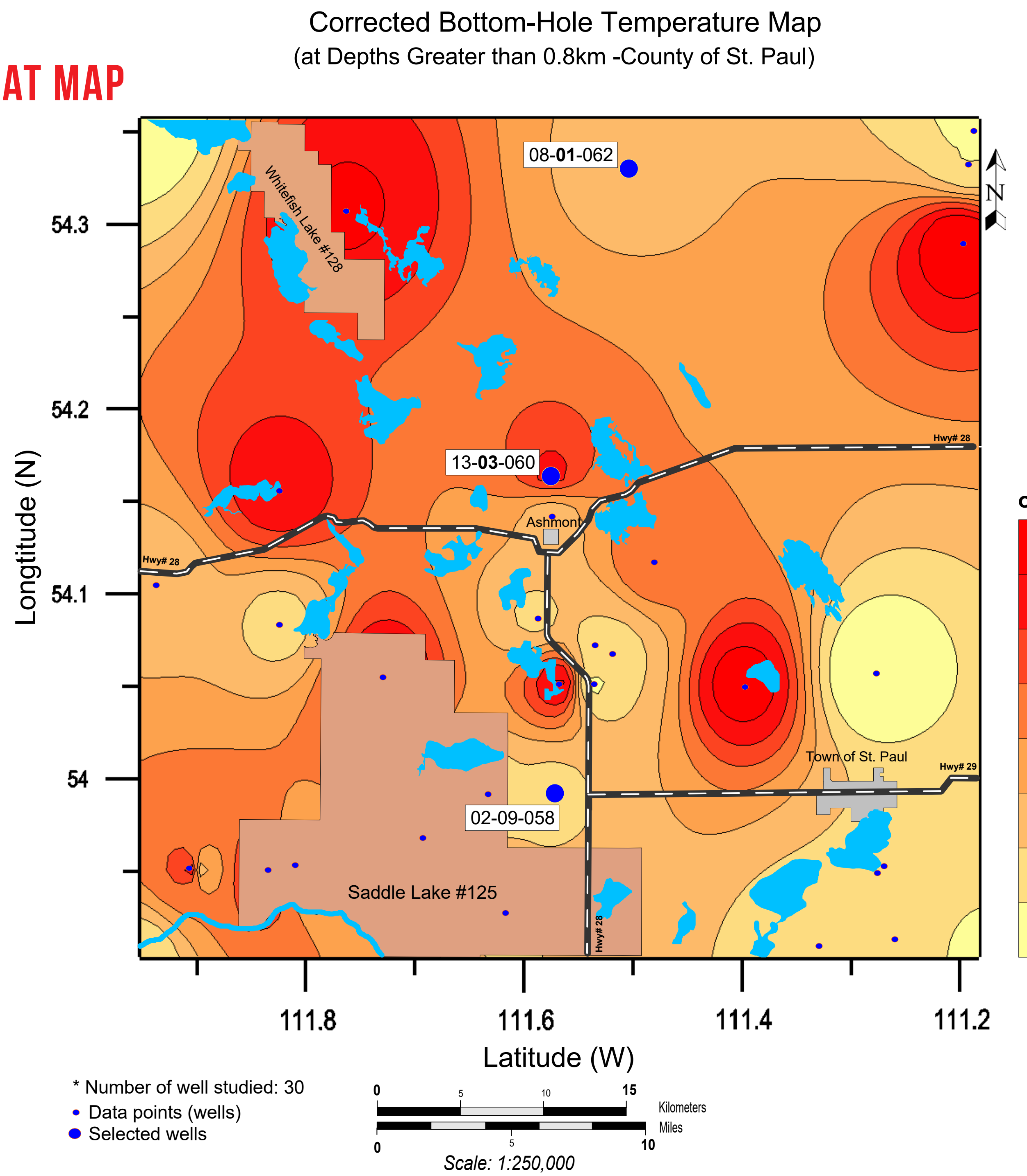
The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

RESEARCH RESULTS: COUNTY OF ST. PAUL

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

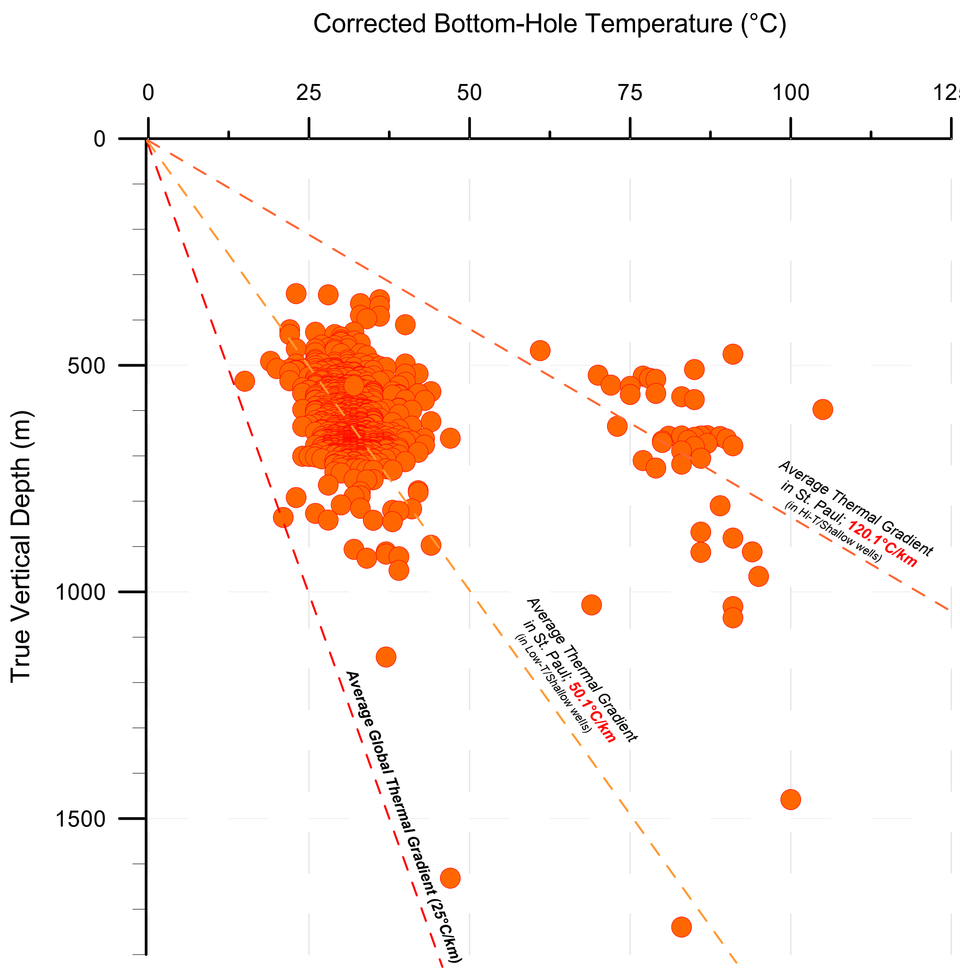
HEAT MAP



RESEARCH RESULTS: COUNTY OF ST. PAUL

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 3 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Watt Mnt F. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/02-09-058-11W4/00	1143	-211.5	37	60	Cdn Nat Rsrcs Ltd
100/08-01-062-11W4/00	1630.9	-699.4	47	60	Nexen Enrg ULC(2)
100/13-03-060-11W4/00	1738.8	-807.3	83	90	Cdn Nat Rsrcs Ltd

KEY TAKEAWAYS

- The only recorded geothermal formation in the study area is the **Watt Mountain** formation.
- The deepest well in the study area was drilled to **1738.8m depth**. The majority of wells are drilled to a depth of less than 1000m.
- There are two sets of bottom hole temperature data. The low temperature set has an average thermal gradient of **50.1°C/km** and the low-moderate set has a thermal gradient of **120.1°C/km**.
- There is potential for **geo-exchange activities** in this area.

RECOMMENDATION & NOTES

Our study of the County of St. Paul has uncovered geological phenomenon that are detrimental to geothermal development. The only recorded geothermal formation in the study area is extremely thin and unlikely to sustain any direct use activities. As well, the majority of wells in the region are extremely shallow and their temperature readings come from less than 1000m depth. This lack of drilled depth compounds potentially anomalous results, improper measurement gathering, or data entry errors and can lead to a severe overestimation of the temperature potential. It is recommended that the County validate the cluster of higher temperature readings and also investigate the opportunity to build geo-exchange systems to take advantage of the relatively stable temperature below the frostline.

September 25, 2018

Geothermal Analysis

Lac La Biche County

Study by Terrapin Geothermics

For further information,
contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

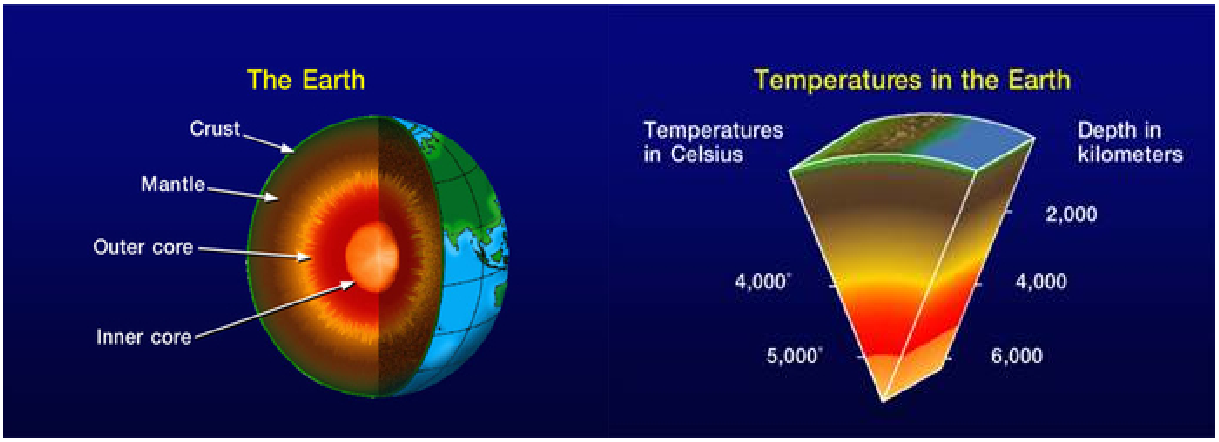
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

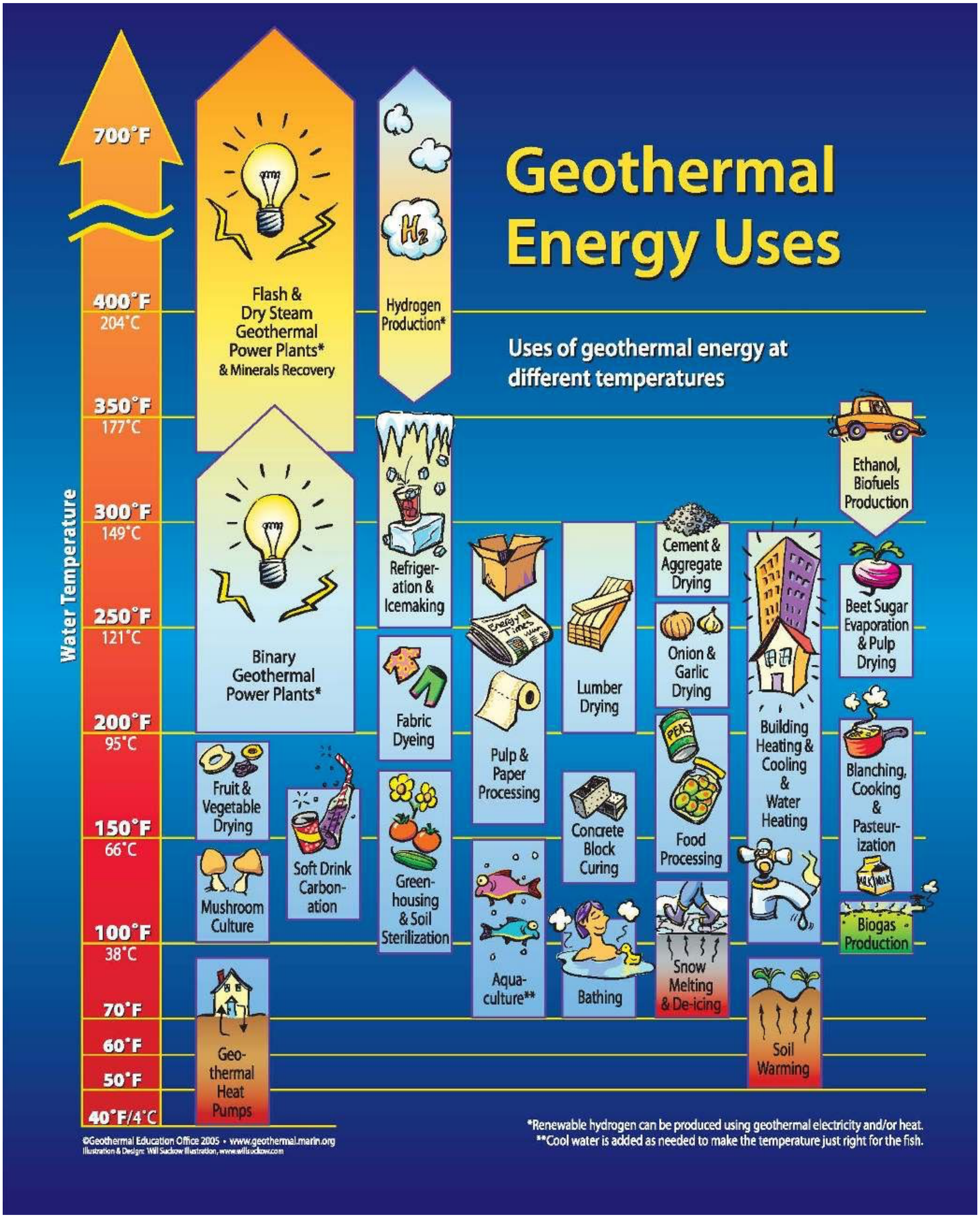
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160^{o}C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180^{o}C and above), medium (100-180^{o}C), and low (80-100^{o}C) temperature resources with fluids under 80^{o}C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235^{o}C or above); flash plants (turning geothermal fluids of at least 150^{o}C into steam to drive a turbine); and binary power plants (using hot waters above 80^{o}C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180^{o}C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

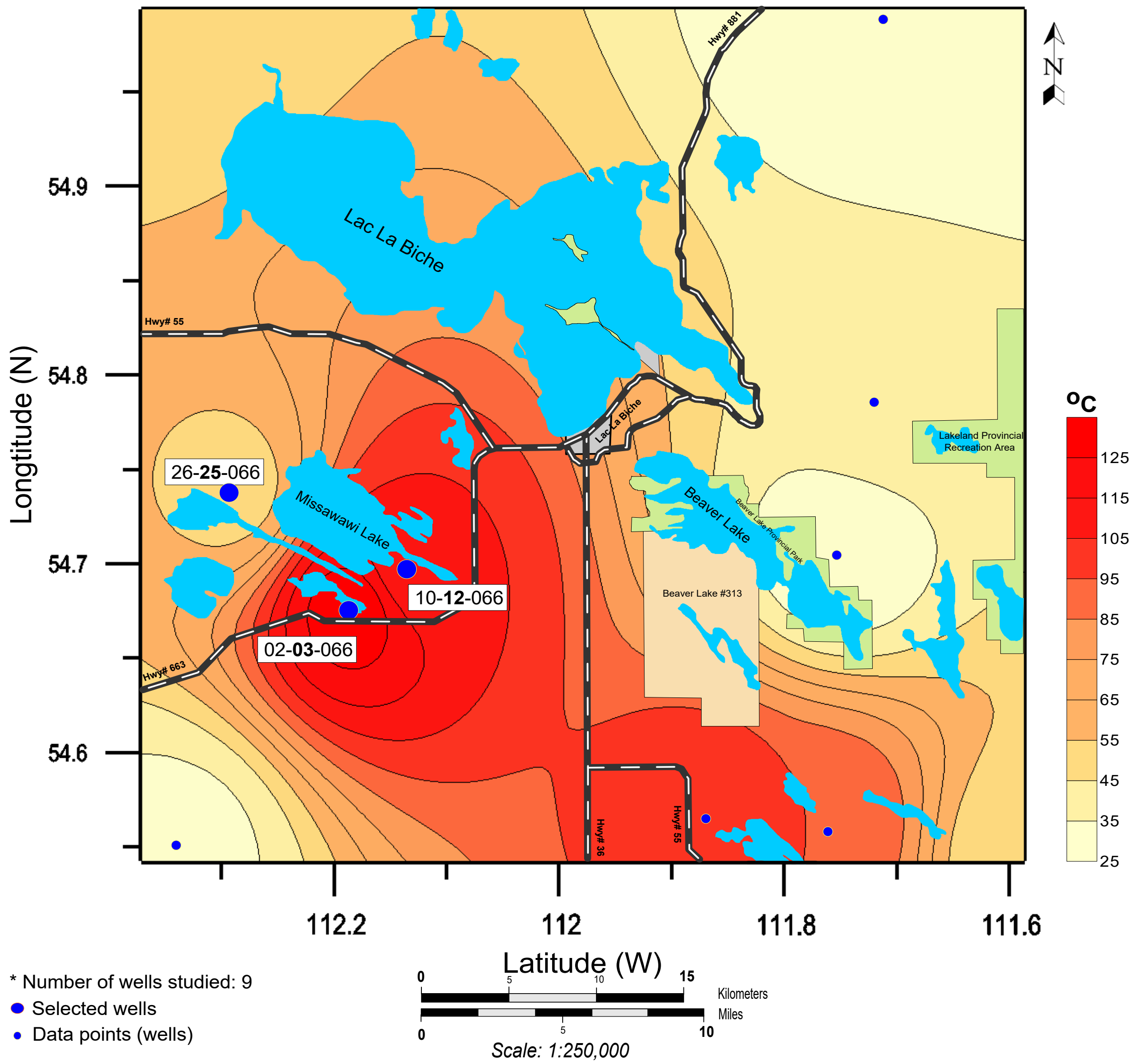
RESEARCH RESULTS: LAC LA BICHE COUNTY

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

HEAT MAP

Corrected Bottom-Hole Temperature Map
(at Depths Greater than 1km - Lac La Biche County)



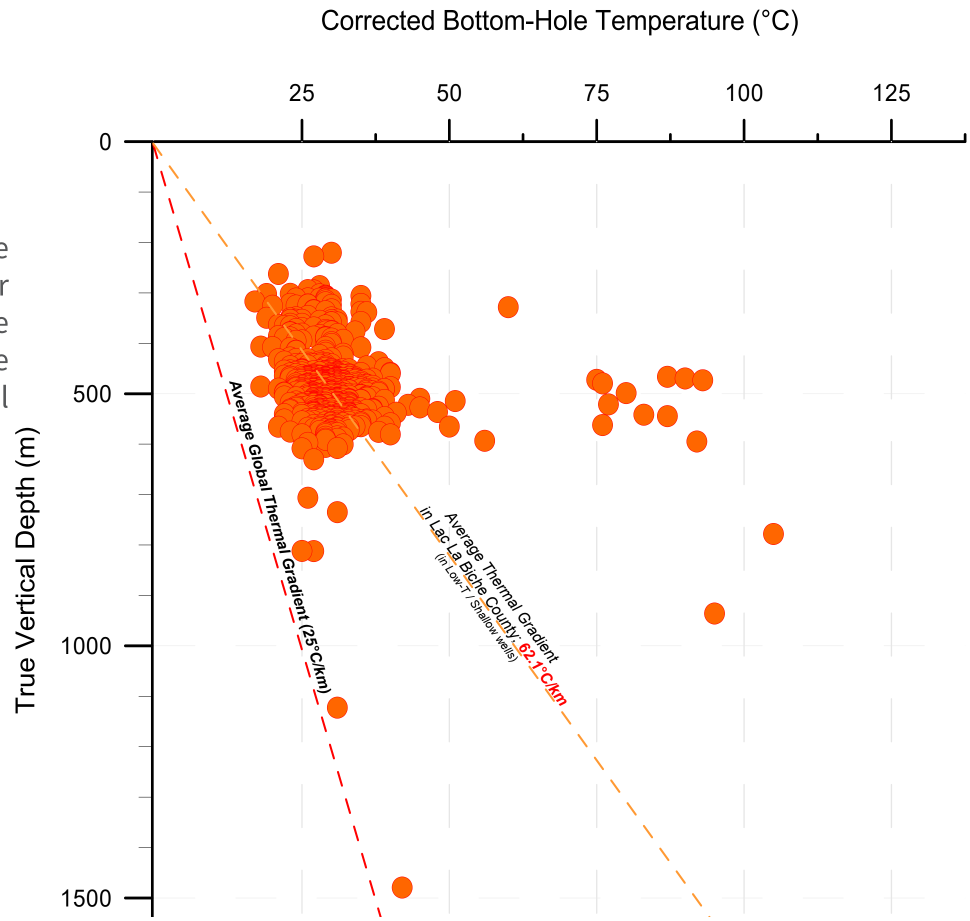
* Number of wells studied: 9
● Selected wells
• Data points (wells)

terrapin

RESEARCH RESULTS: LAC LA BICHE COUNTY

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 3 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Watt Mnt. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/10-12-066-15W4/00	1587.5	-602.5	107	120	Suncor Enrg Inc
100/02-03-066-15W4/00	1610.8	-620.2	131	150	Suncor Enrg Inc
100/06-25-066-16W4/00	1615.7	-619.8	51	80	Repsol O&G Cda Inc

KEY TAKEAWAYS

- The potential geothermal formation reached in your area is the **Watt Mountain** formation.
- The Precambrian basement is very **shallow** in your area, occurring at **1600m**.
- There is a high geothermal gradient in your area of **62.1°C/km**.
- Using currently available data, there is strong potential for **geo-exchange activities** to occur in your area.

RECOMMENDATION & NOTES

Our study of Lac La Biche County has uncovered geological phenomenon that are detrimental to geothermal development. The only recorded geothermal formation in the study area is extremely thin (approximately 20m thick). This thinness makes it unlikely that the formation could sustain any direct use activities. As well, the majority of wells in the region are extremely shallow and their temperature readings come from less than 750m depth. This lack of drilled depth compounds potentially anomalous results, improper measurement gathering, or data entry errors and can lead to a severe overestimation of the temperature potential. It is recommended that the County investigate the opportunity to build geo-exchange systems to take advantage of the relatively stable temperature below the frostline.

September 25, 2018

Geothermal Analysis

Municipal District of Bonnyville

Study by Terrapin Geothermics

terrapin

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

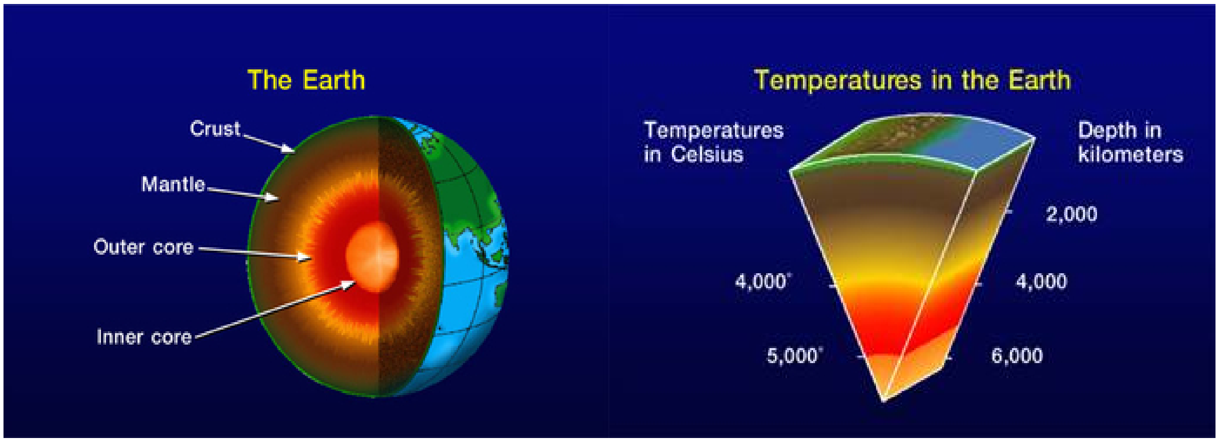
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

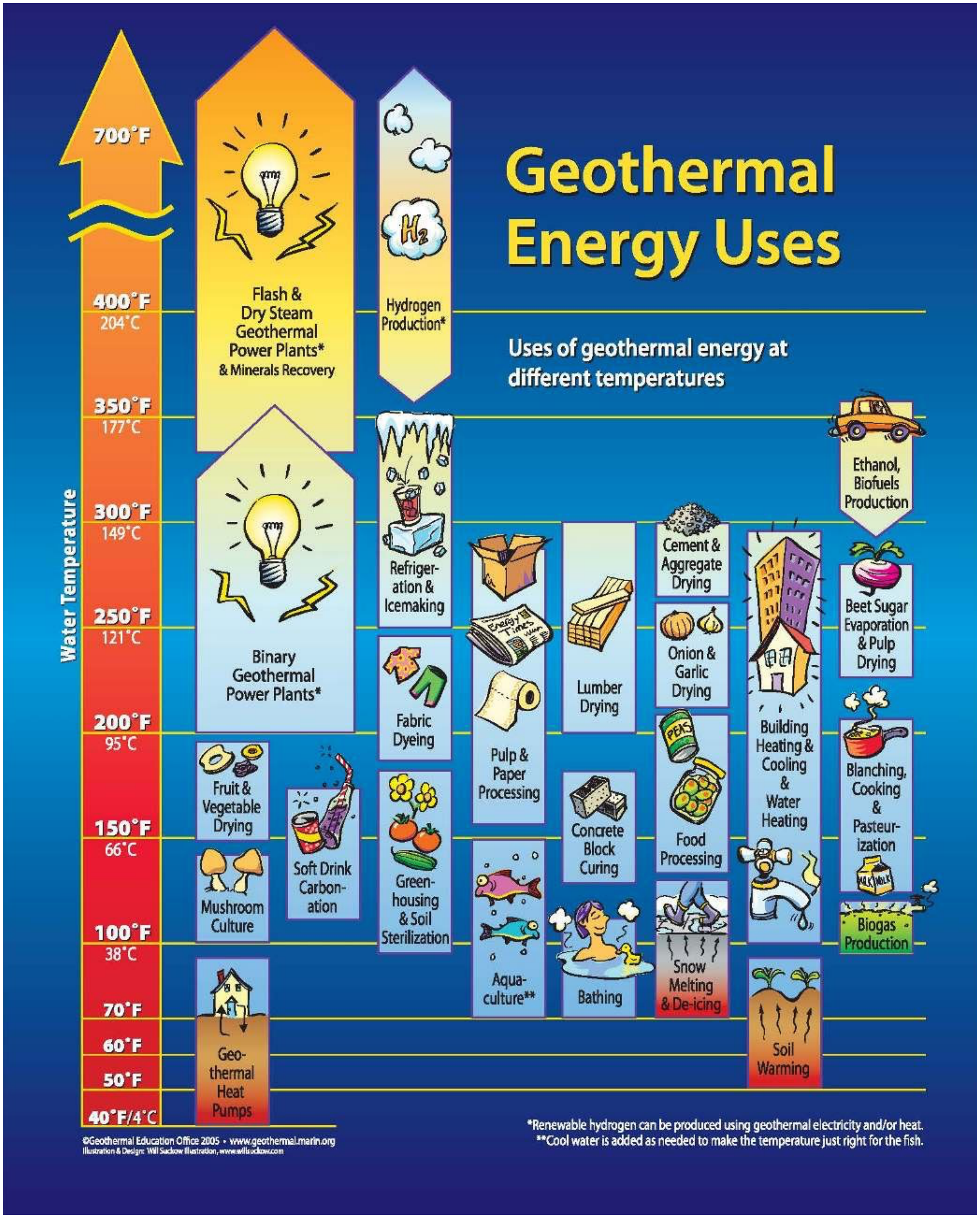
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180°C and above), medium (100-180°C), and low (80-100°C) temperature resources with fluids under 80°C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235°C or above); flash plants (turning geothermal fluids of at least 150°C into steam to drive a turbine); and binary power plants (using hot waters above 80°C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180°C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

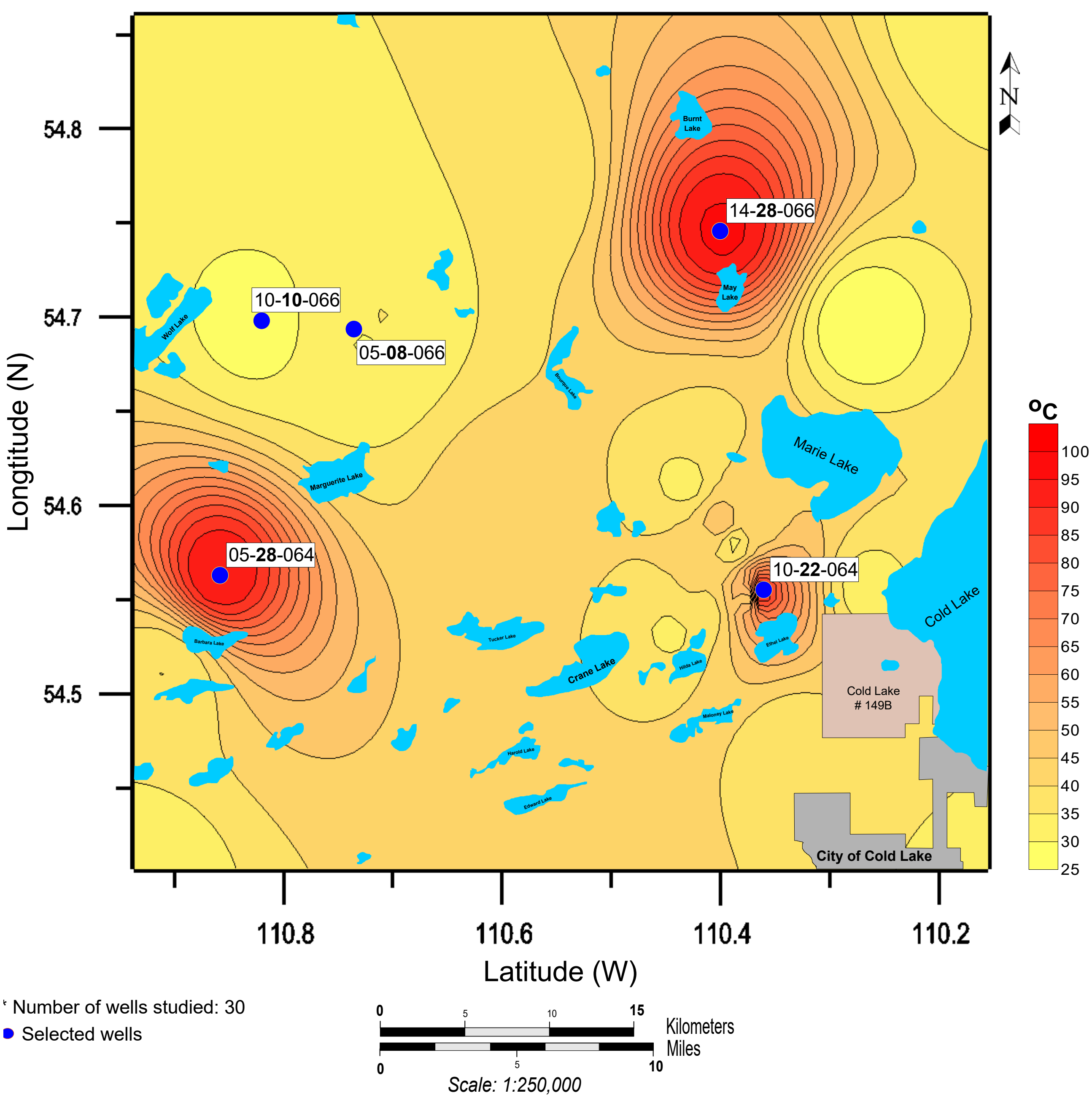
The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

Corrected Bottom-Hole Temperature Map
(at Depths Greater than 1.2 km - MD of Bonnyville)

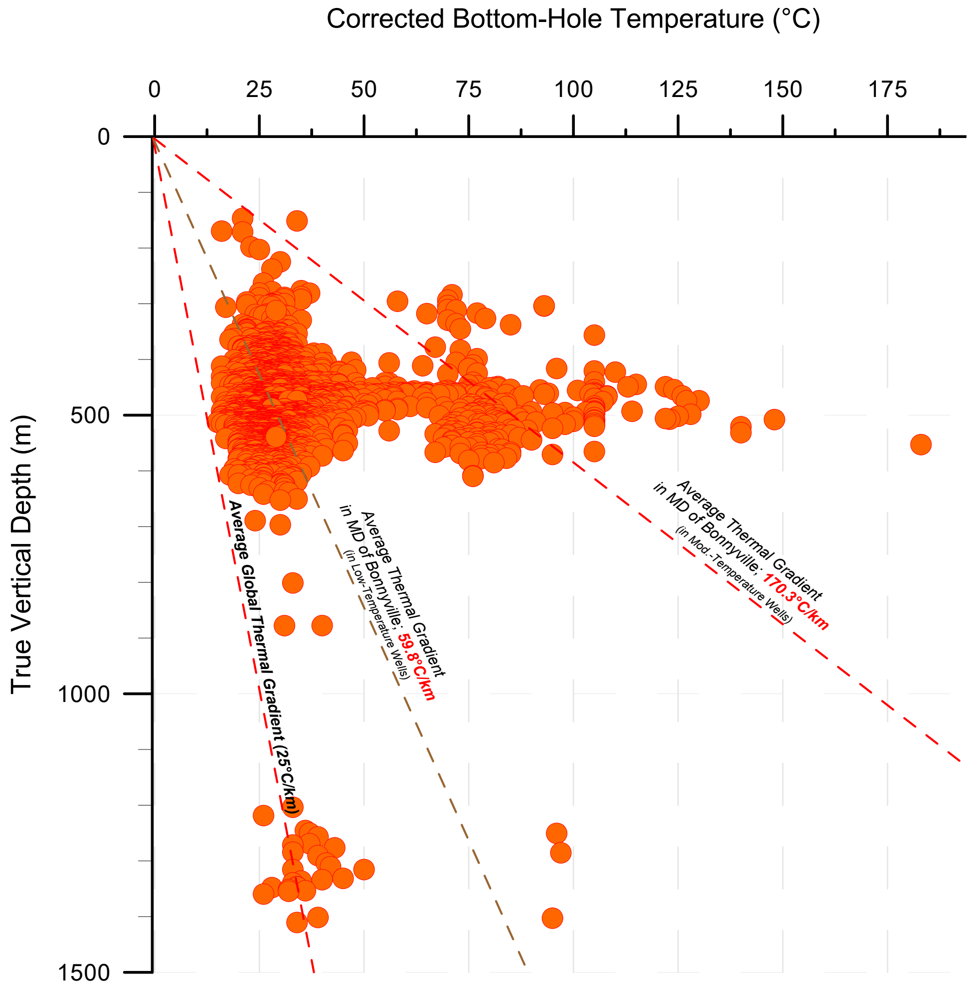
HEAT MAP



RESEARCH RESULTS: M.D. OF BONNYVILLE

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 5 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Devonian Strata (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
1AA/14-28-066-03W4/00	2930.8	-699.8	96	120	Imperial Oil Rsrcs Ltd(2)
1AE/10-22-064-03W4/00	2843	-734.6	97	120	Imperial Oil Rsrcs Ltd(2)
100/05-08-066-05W4/00	2783.1	-832.2	32	60	Cdn Nat Rsrcs Ltd
100/10-10-066-06W4/00	2705.4	-746.5	26	60	BP Cda Enrg Grp ULC
100/05-28-064-06W4/00	2571.3	-889.4	95	120	Plains Midstream Cda ULC

KEY TAKEAWAYS

- The identified productive geothermal formation underlying the study area is the **Granite Wash** formation.
- The indicated geothermal gradient in your area is **59.8ºC/km** and is likely influenced by the shallowness of the study area's wells.
- The majority of wells in the study area are drilled to less than **700m depth.**
- There is potential for **geo-exchange** activities in the study area

RECOMMENDATION & NOTES

The wells studied in the M.D. of Bonnyville are quite shallow and provide little data that can be used to make accurate geothermal assumptions. It is likely that the geothermal gradient in the area is lower than indicated. A lack of drilled depth compounds potentially anomalous results, improper measurement gathering, or data entry errors and can lead to a severe overestimation of the temperature potential. We recommend that the M.D. validate the identified temperatures, as well as pursue the opportunity to build geo-exchange systems to take advantage of the relatively stable temperature below the frostline.

September 25, 2018

Geothermal Analysis

Municipal District of Fairview

Study by Terrapin Geothermics

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

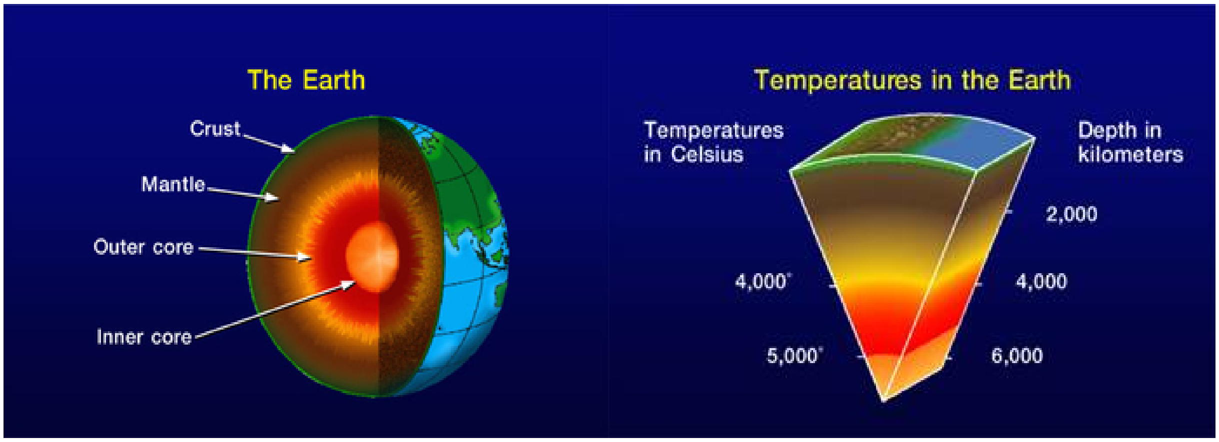
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

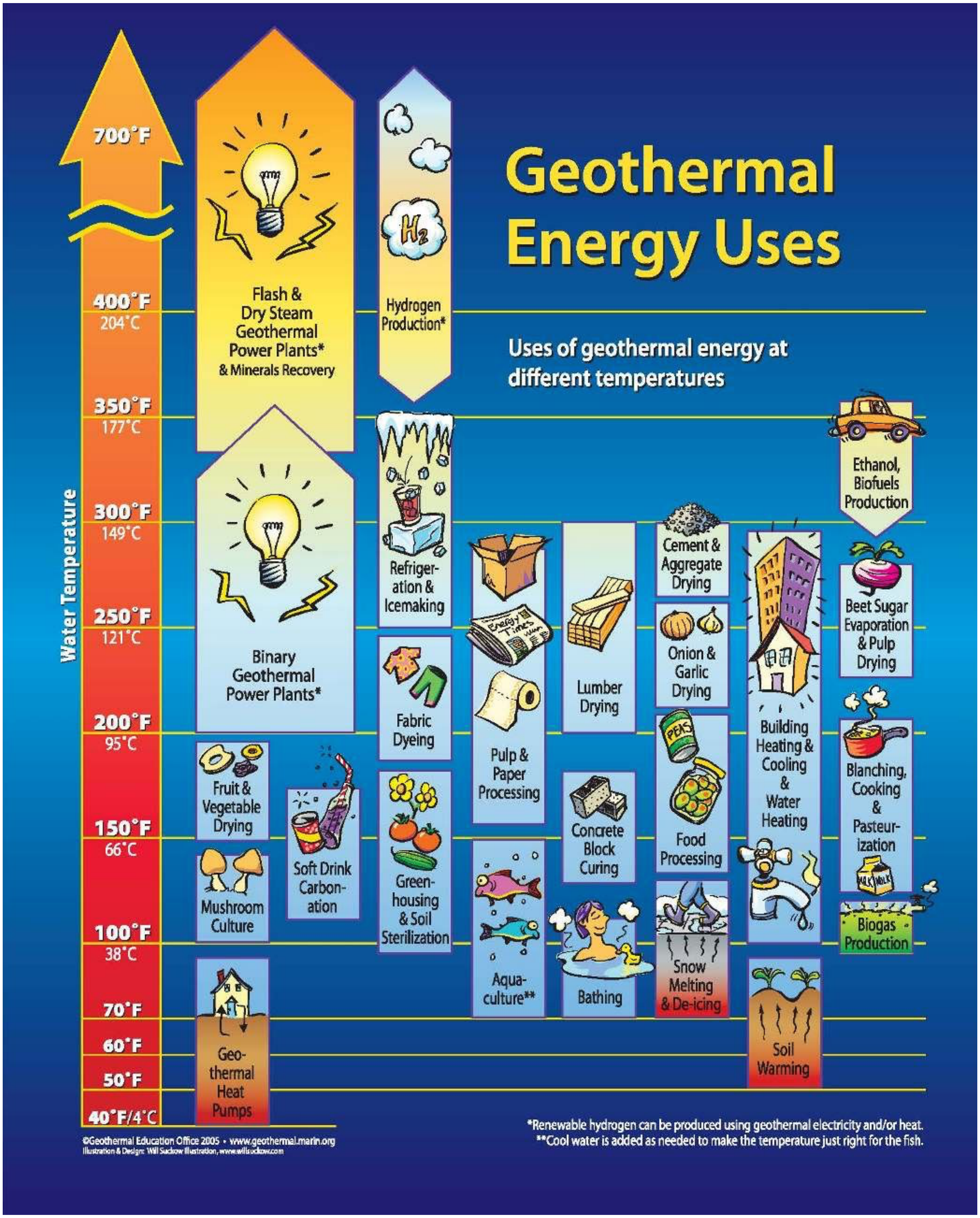
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180°C and above), medium (100-180°C), and low (80-100°C) temperature resources with fluids under 80°C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235°C or above); flash plants (turning geothermal fluids of at least 150°C into steam to drive a turbine); and binary power plants (using hot waters above 80°C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180°C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

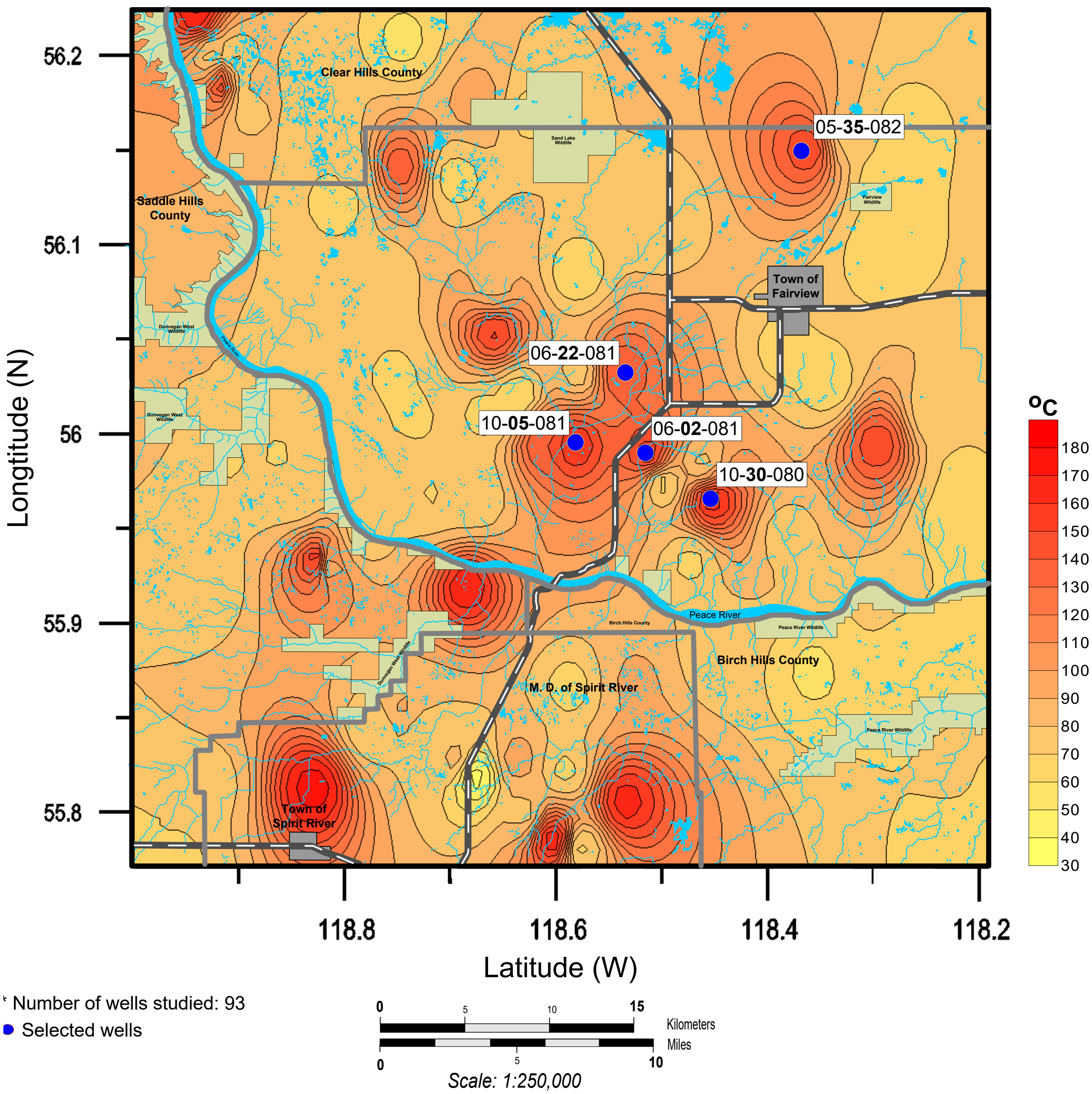
RESEARCH RESULTS: M.D. OF FAIRVIEW

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

HEAT MAP

Corrected Bottom-Hole Temperature Map
(at Depths Greater than 2km - M. D. of Fairview)

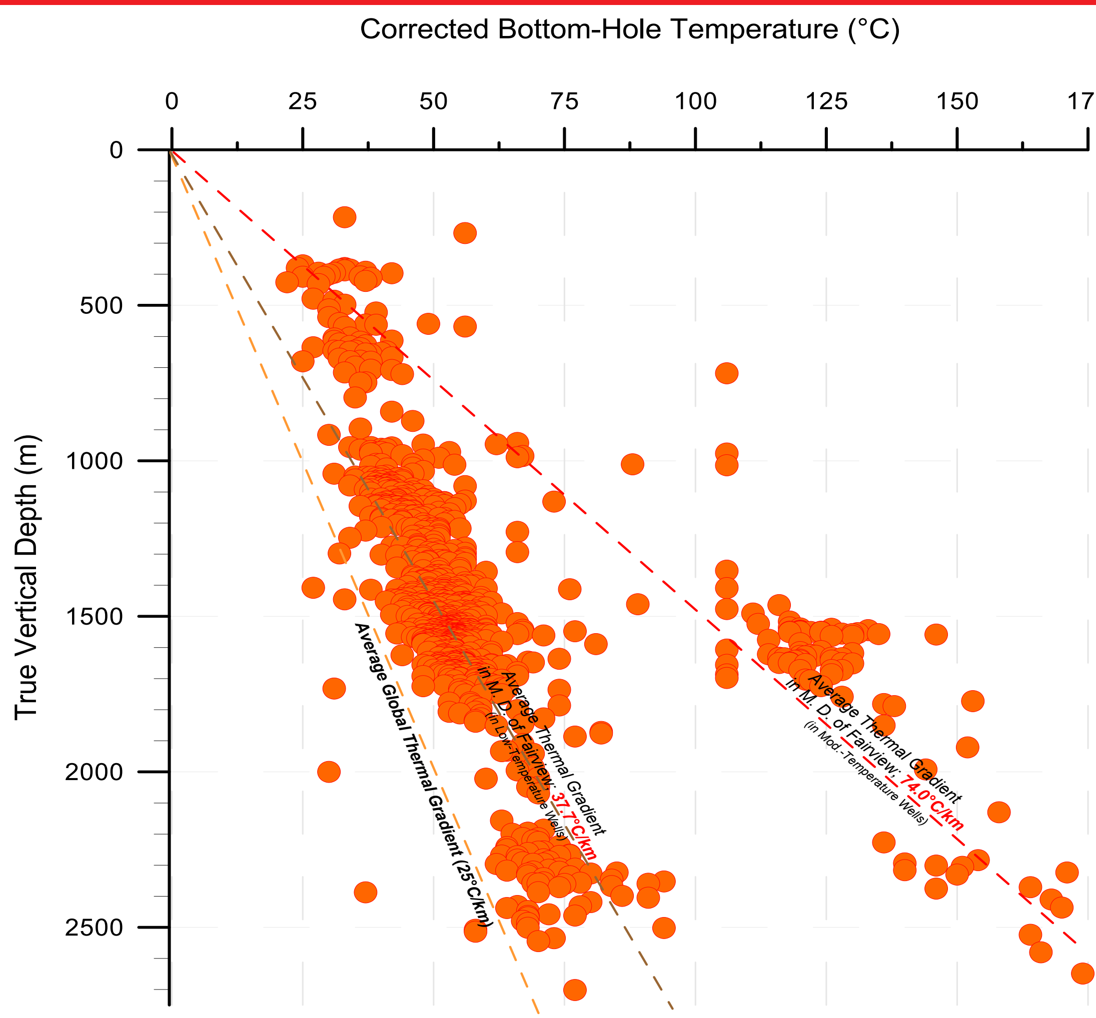


* Number of wells studied: 93
Selected wells

RESEARCH RESULTS: M.D. OF FAIRVIEW

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 5 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Granite Wash F. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/05-35-082-03W6/00	2300.6	-50.6	146	150	177293 Cda Ltd
100/06-02-081-04W6/00	2283.2	-19.5	154	160	Cdn Nat Rsrcs Ltd
100/10-30-080-03W6/00	2370.1	-73.8	164	170	Transocean Oil Inc
100/10-05-081-04W6/00	2129.3	-42.7	158	160	Transocean Oil Inc
100/06-22-081-04W6/00	2315.5	-23.7	140	150	Cdn Nat Rsrcs Ltd

KEY TAKEAWAYS

- The identified productive geothermal formation in your area is the **Granite Wash** formation
- There are two temperature data sets in the study area: a low-moderate set with an indicated gradient of **37.7ºC/km** and a moderate-high set with an indicated temperature gradient of **74ºC/km.** These are both significantly higher than the global average.
- There is potential for **geo-exchange and possible direct-use** activities in the study area

RECOMMENDATION & NOTES

Our investigation of the M.D. of Fairview has uncovered a number of beneficial and potentially detrimental factors for geothermal development. There are consistently superior temperature readings that increase with well depth. However, though the Devonian strata has a moderate thickness (300m), the only identified productive geothermal formation in the study area is relatively thin (60m). Therefore, the productive formation may be hot enough to support sustained geothermal production but may not contain the necessary energy content. It is recommended that the studies encompassing the entire county be undertaken which validate the high temperature well data, find areas with thicker sedimentary cover, and examine water production from hydrocarbon extraction activities to provide an indication as to the water content of the potential geothermal formation.

September 25, 2018

Geothermal Analysis

Municipal District of Lesser Slave River

Study by Terrapin Geothermics

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

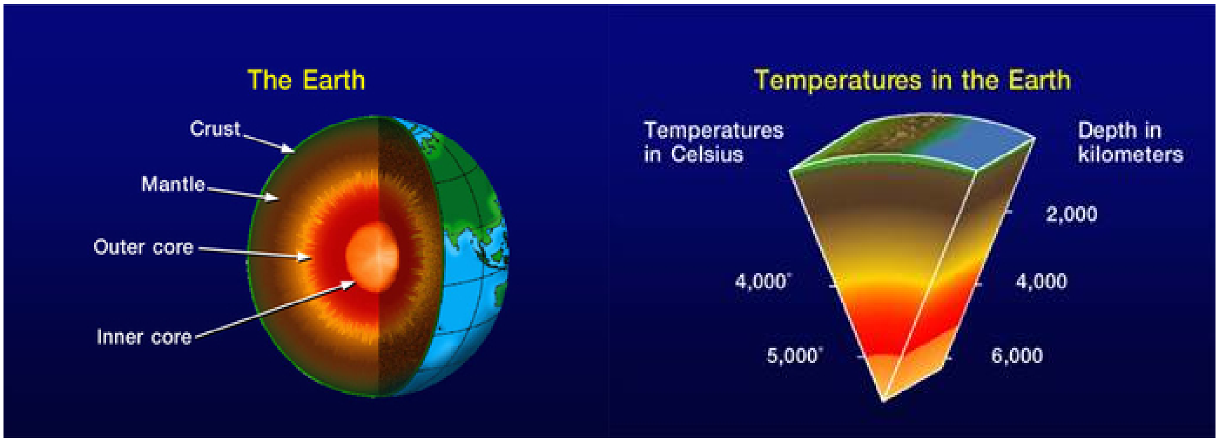
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

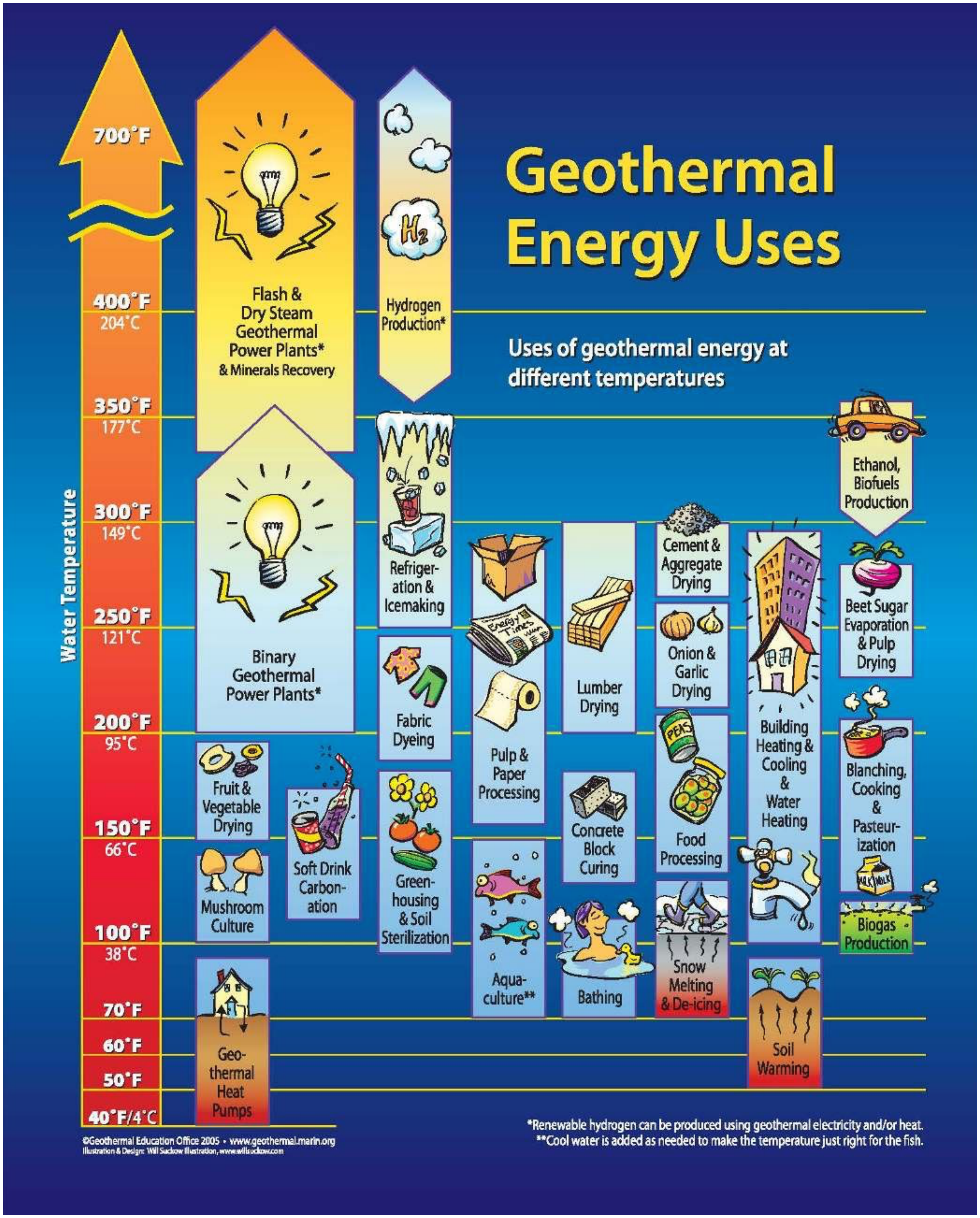
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180ºC and above), medium (100-180ºC), and low (80-100ºC) temperature resources with fluids under 80ºC being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235ºC or above); flash plants (turning geothermal fluids of at least 150ºC into steam to drive a turbine); and binary power plants (using hot waters above 80ºC to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180ºC.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

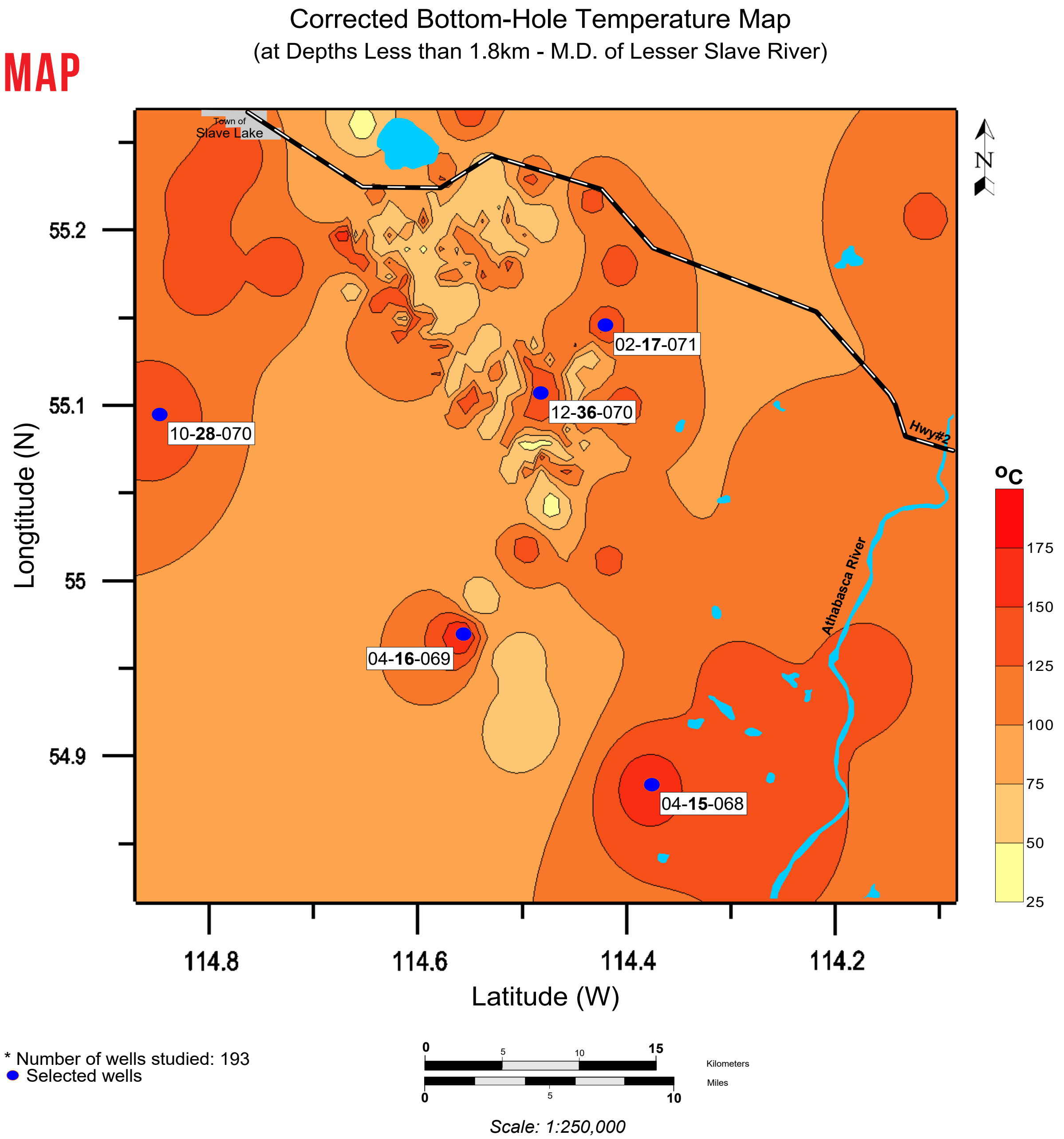
The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

RESEARCH RESULTS: M.D. OF LESSER SLAVE RIVER

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

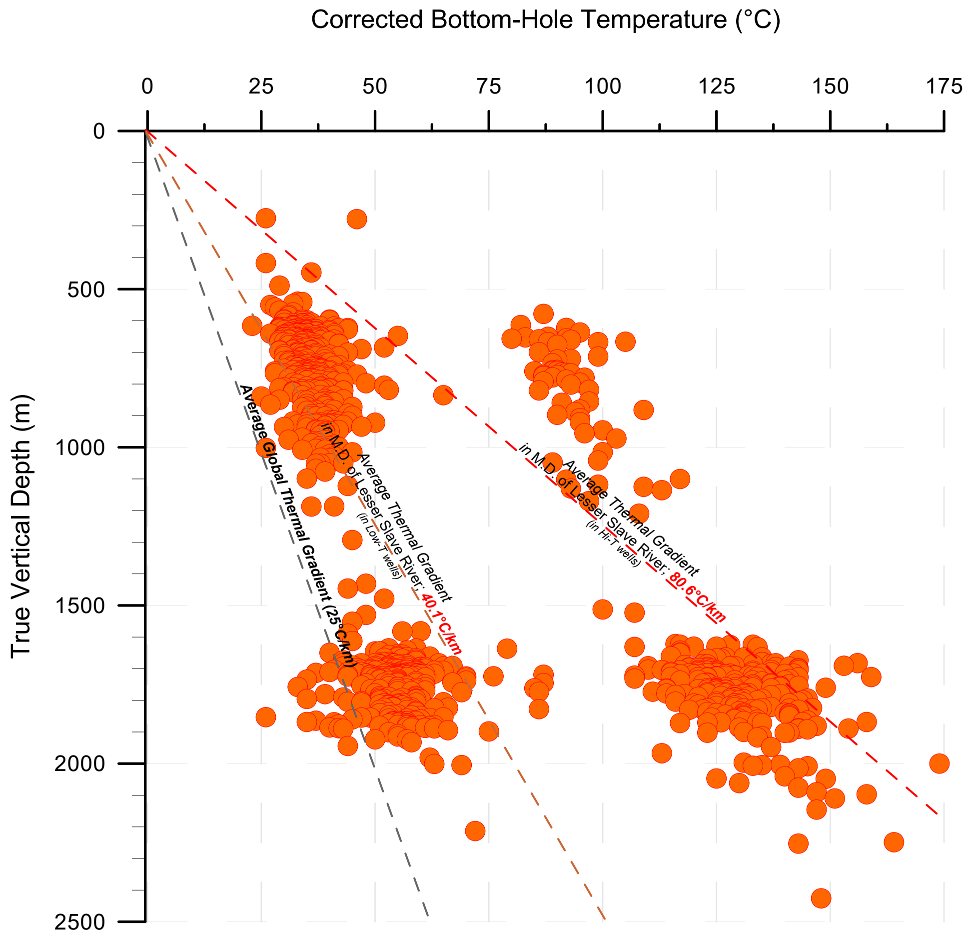
HEAT MAP



RESEARCH RESULTS: M.D. OF LESSER SLAVE RIVER

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 5 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Gilwood. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/10-28-070-06W5/00	2425.1	-288.5	148	160	Devon Cda Corp
100/04-16-069-04W5/00	2247.7	-325.8	164	180	BP Cda Enrg Grp ULC
100/12-36-070-04W5/00	2144.6	-339	147	160	Cardinal Enrg Ltd(2)
100/02-17-071-03W5/00	2109.3	-350	151	160	Devon Cda Corp
100/04-15-068-03W5/00	2096.2	-390.2	158	160	Chevron Cda Ltd

KEY TAKEAWAYS

- The identified productive geothermal formations in your area are the **Gilwood Member** and the **Leduc Formation**.
- There are two temperature data sets in the study area: a low-moderate set with an indicated gradient of **40.1°C/km** and a moderate-high set with an indicated temperature gradient of **80.6°C/km.** These are both significantly higher than the global average.
- There is potential for **direct use and power generation** activities in the study area.

RECOMMENDATION & NOTES

Our investigation of the geothermal potential in the M.D. of Lesser Slave River has uncovered several beneficial factors for geothermal development. There are clusters of temperature readings which indicate the ability to support direct-use and/or power generation activities. Geologically, the Gilwood ranges in thickness from 20-250m and the Leduc is approximately 160m. Therefore, the productive formations are hot enough to support geothermal production and may contain large volumes of fluids. It is recommended that further studies be undertaken, encompassing the entire M.D., which validate the temperature data, find areas of thick sedimentary cover, and examine water production from hydrocarbon activities to provide an indication of the fluid content of the potential geothermal formation.

September 25, 2018

Geothermal Analysis

Municipal District of Opportunity

Study by Terrapin Geothermics

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

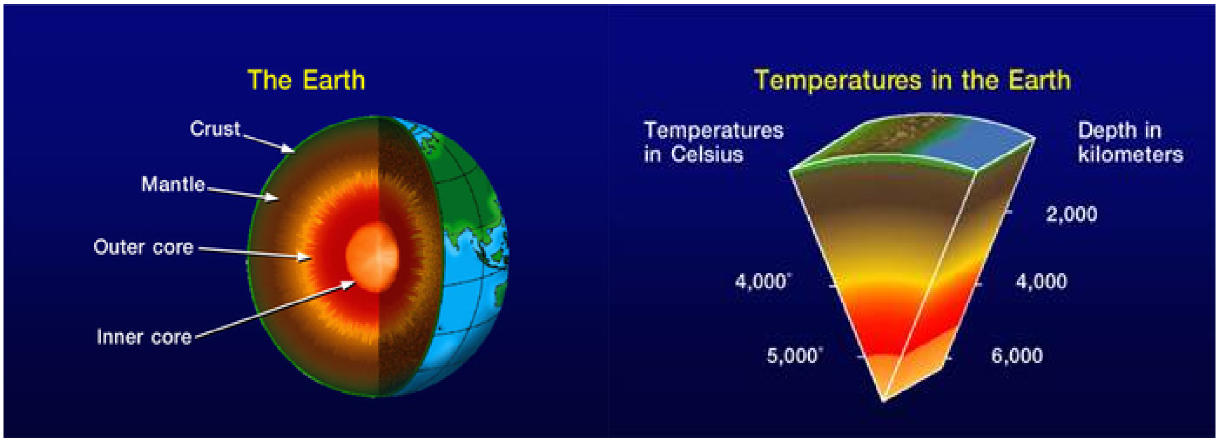
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

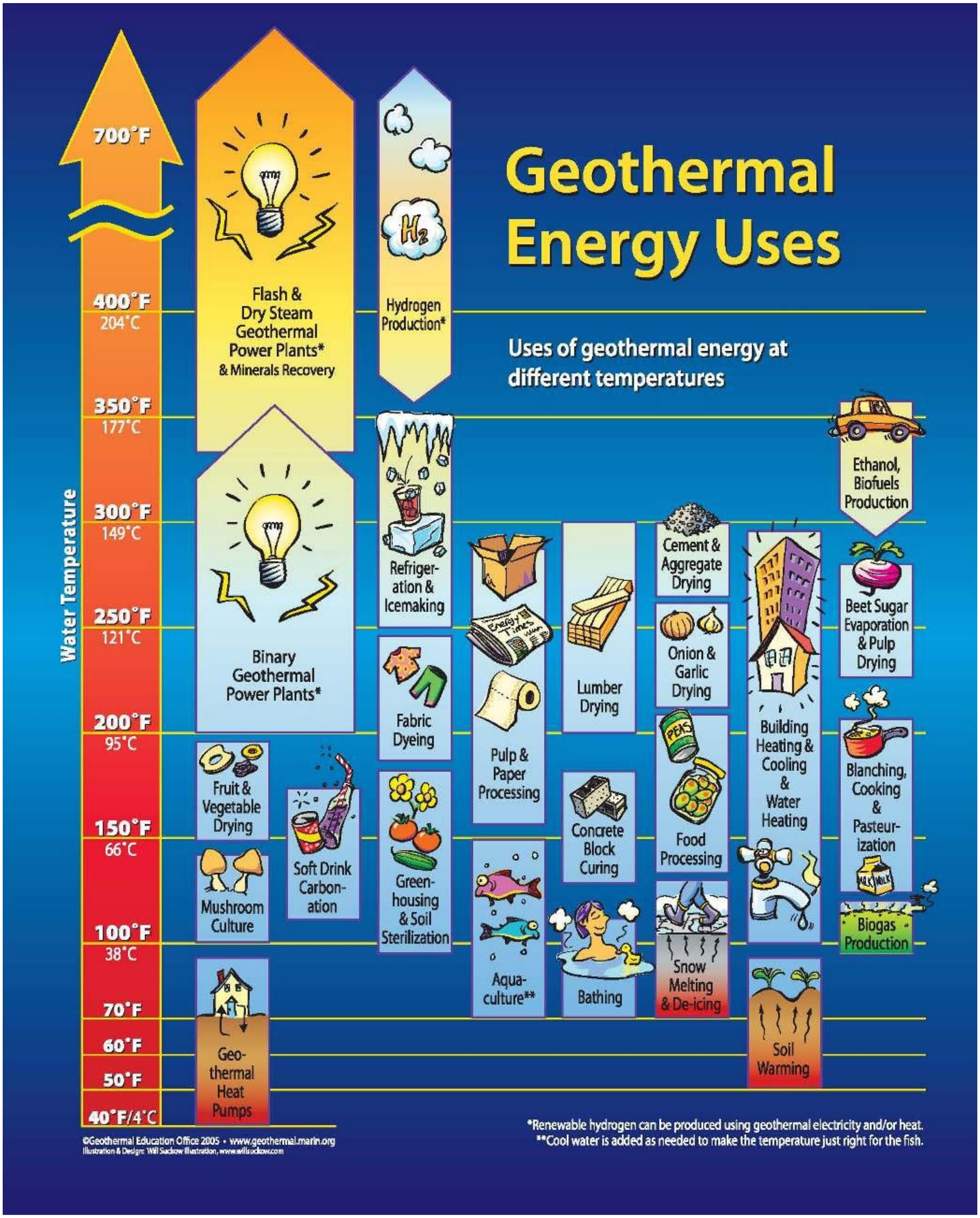
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180^{o}C and above), medium (100-180^{o}C), and low (80-100^{o}C) temperature resources with fluids under 80^{o}C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235^{o}C or above); flash plants (turning geothermal fluids of at least 150^{o}C into steam to drive a turbine); and binary power plants (using hot waters above 80^{o}C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180^{o}C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

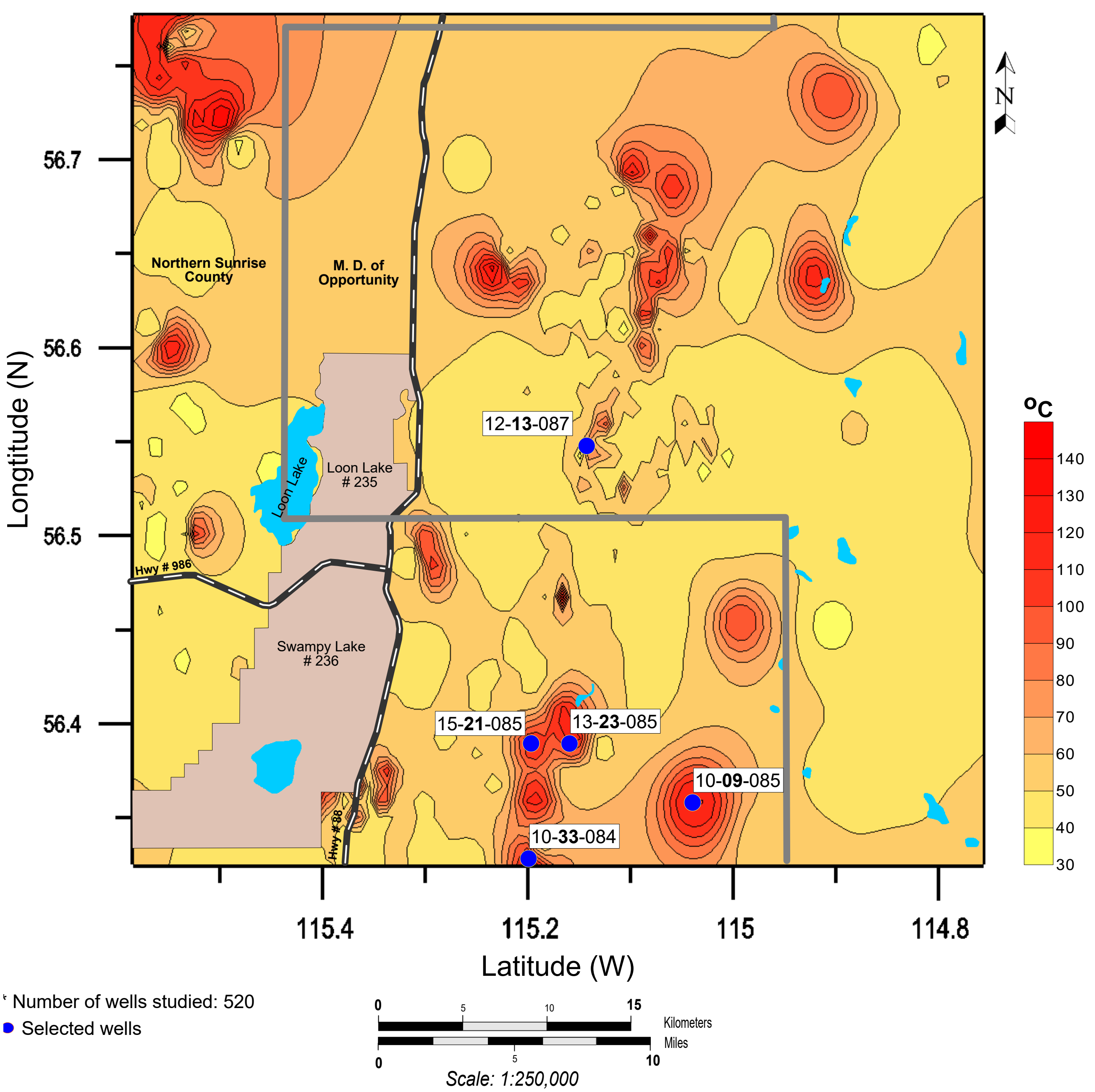
RESEARCH RESULTS: M.D. OF OPPORTUNITY

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

HEAT MAP

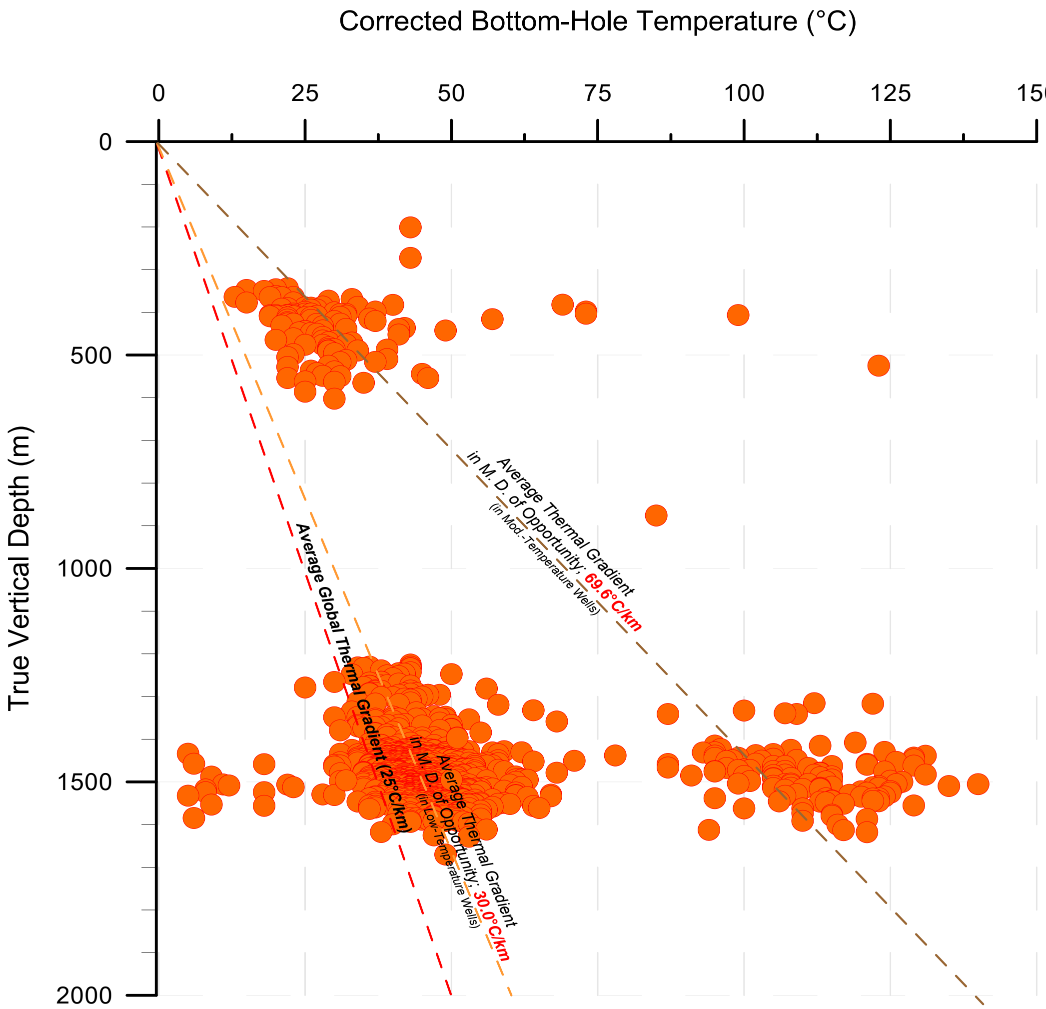
Corrected Bottom-Hole Temperature Map
(at Depths Greater than 1.5km - M. D. of Opportunity)



RESEARCH RESULTS: M.D. OF OPPORTUNITY

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 5 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Granite Wash F. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/10-09-085-07W5/00	1617.2	-21.3	121	120	BP Cda Enrg Grp ULC
100/10-33-084-08W5/00	1612.4	-33.2	117	120	Suncor Enrg Inc(2)
100/12-13-087-08W5/00	1611.7	-106.6	94	100	Mount Bastion O&G Corp
100/13-23-085-08W5/00	1599.6	-65.5	116	120	Inter-City Gas Corp
100/15-21-085-08W5/00	1590.5	-42.9	110	120	Devon Cda Corp

KEY TAKEAWAYS

- The identified productive formation in your region is the **Granite Wash** formation
- There are two temperature data sets in the study area. The low-moderate data set indicates a gradient of **30ºC/km** and the moderate-high data set shows a gradient of **69.6ºC/km**.
- There is strong potential for **direct-use** activities in the study area and indications of possible **power generation** opportunities.

RECOMMENDATION & NOTES

Our study of the MD of Opportunity has uncovered a number of geological phenomenon that are beneficial to geothermal development. The Devonian-aged formations are incredibly thick, more than 1km total, in the study area. This thickness indicates an ability for the formations to store large amounts of fluid and heat. As well, there are indications of geological structures in the region that will likely promote subsurface fluid flows. It is strongly recommended that the MD of Opportunity pursue further targeted research into its geothermal potential. Specific research should include an investigation of additional geological structures and/or anomalies in the MD; investigating the local porosity and permeability within the Devonian-aged formations; and the creation of detailed energy potential models to assess the magnitude of this opportunity.

September 25, 2018

Geothermal Analysis

Municipal District of Peace

Study by Terrapin Geothermics

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above 0^{o}C.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

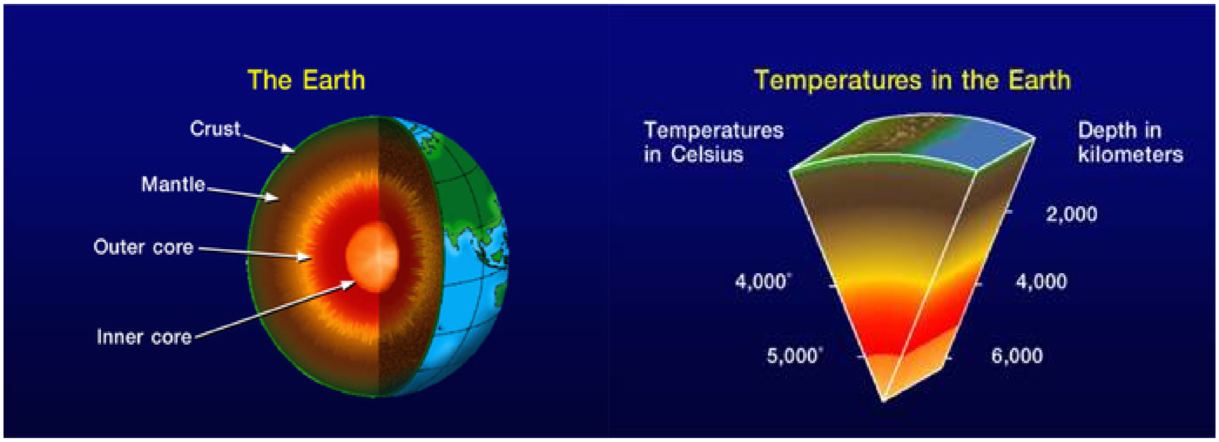
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

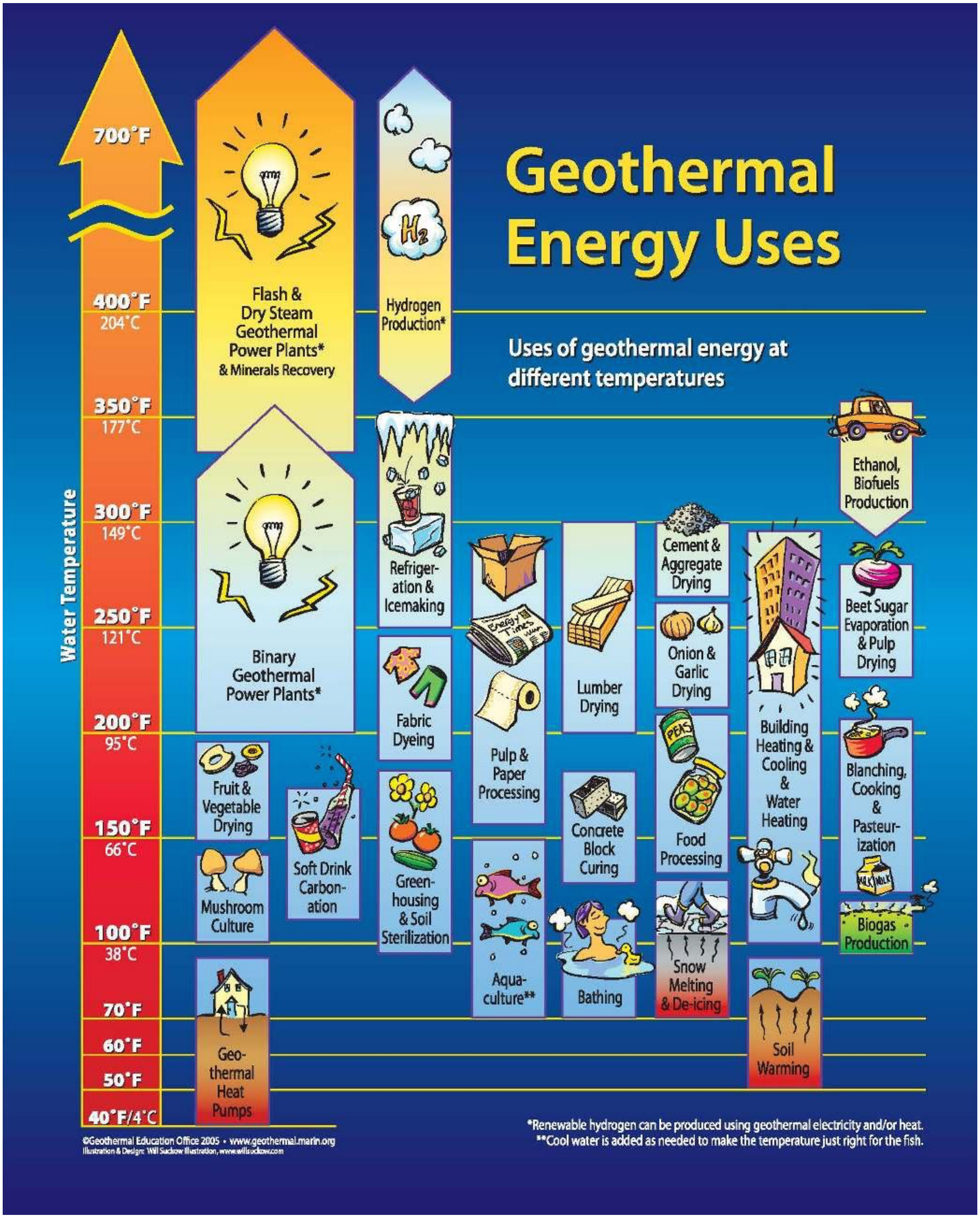
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000°C, for comparison, the temperature on the surface of the sun is approximately 5,500°C. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180^{o}C and above), medium (100-180^{o}C), and low (80-100^{o}C) temperature resources with fluids under 80^{o}C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235^{o}C or above); flash plants (turning geothermal fluids of at least 150^{o}C into steam to drive a turbine); and binary power plants (using hot waters above 80^{o}C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180^{o}C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

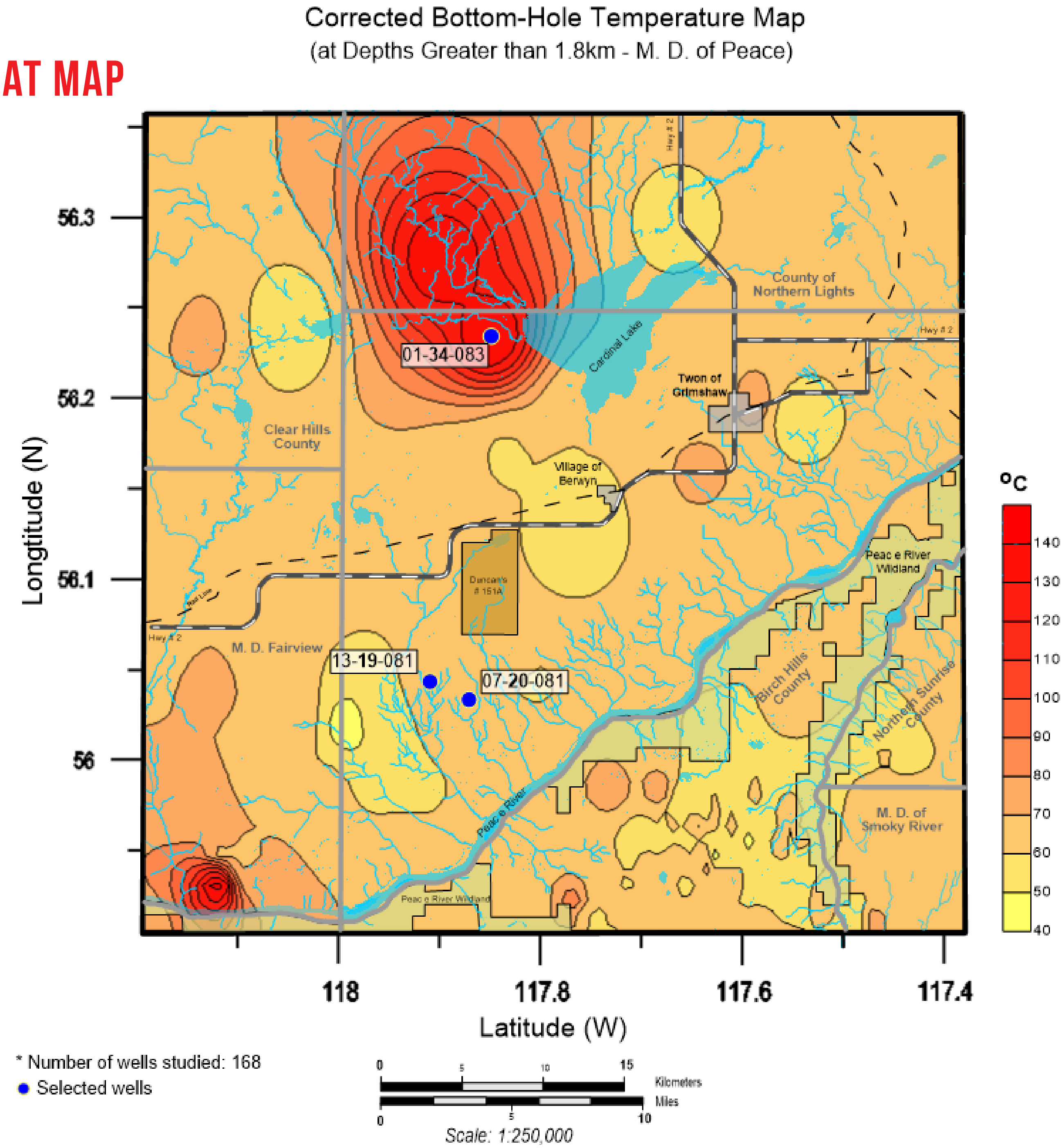
The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

RESEARCH RESULTS: M.D. OF PEACE

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

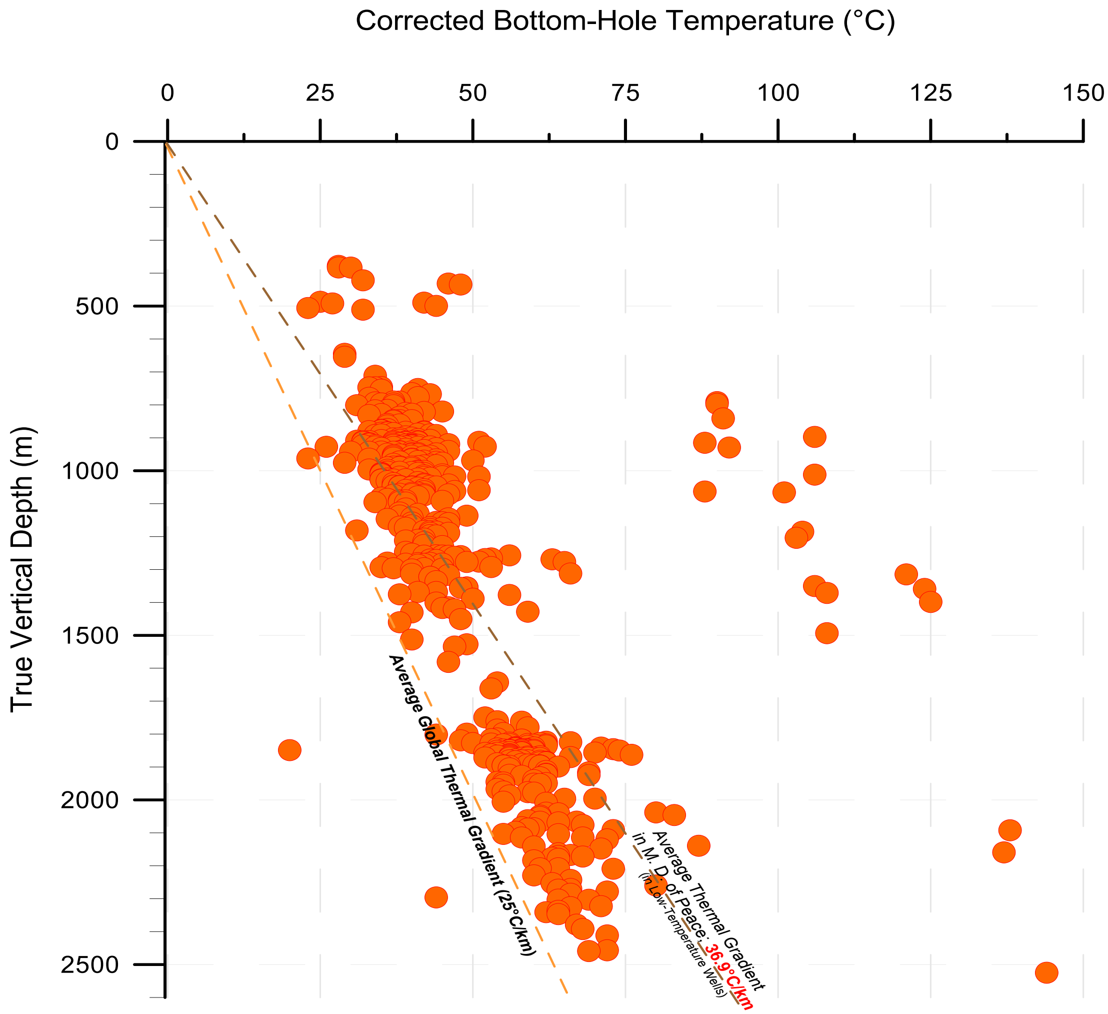
HEAT MAP



RESEARCH RESULTS: M.D. OF PEACE

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 3 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Granite Wash F. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/14-25-085-19W5/00	2091.2	-16.5	138	140	Devon Cda Corp
100/08-28-083-18W5/00	2339.9	-34.6	62	90	BP Cda Enrg Grp ULC
100/13-11-084-17W5/00	2336	-100	64	90	Forest Oil Corp

KEY TAKEAWAYS

- The identified geothermal formation in the study area is the **Granite Wash** formation
- The indicated geothermal gradient in the study area is **36.9ºC/km**. That is **48% greater** than the global average.
- There is potential for **direct use** opportunities in the M.D., particularly in the northwestern corner of the study area.

RECOMMENDATION & NOTES

Our investigation of the M.D. of Peace has uncovered a number of beneficial and potentially detrimental factors to geothermal development. There are clusters of excellent temperature readings registered in wells which indicate the ability to support direct-use activities. Geologically, the Devonian strata underlying the study area has an average thickness of 411m but the previously identified geothermal formation has a maximum thickness of 100m. Therefore, the productive formation may be hot enough to support sustained geothermal production but it may not contain sufficient energy content. It is recommended that the studies be undertaken which validate the high temperature data and examine the water production from hydrocarbon extraction activities to provide an indication as to the water content of the potential geothermal formation.

September 25, 2018

Geothermal Analysis

Municipal District of Smoky River

Study by Terrapin Geothermics

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

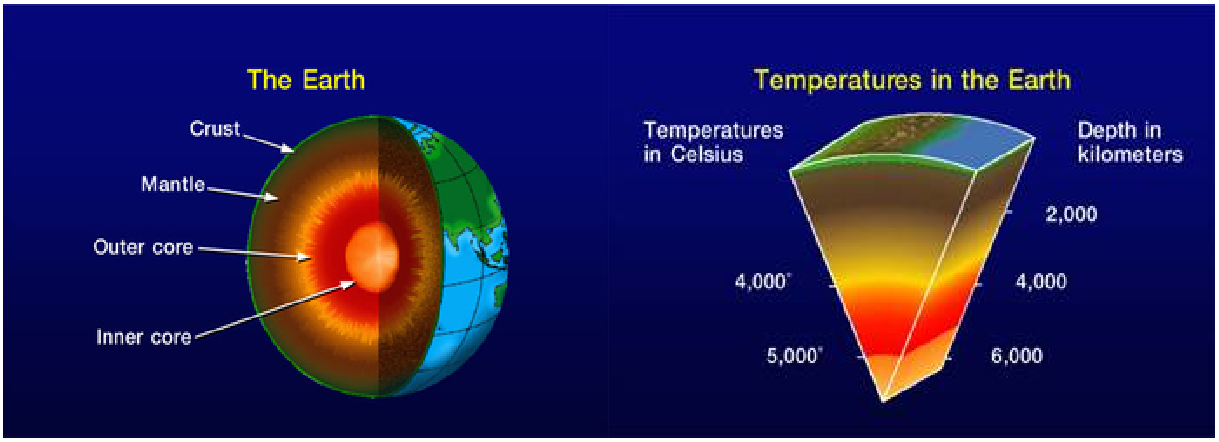
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

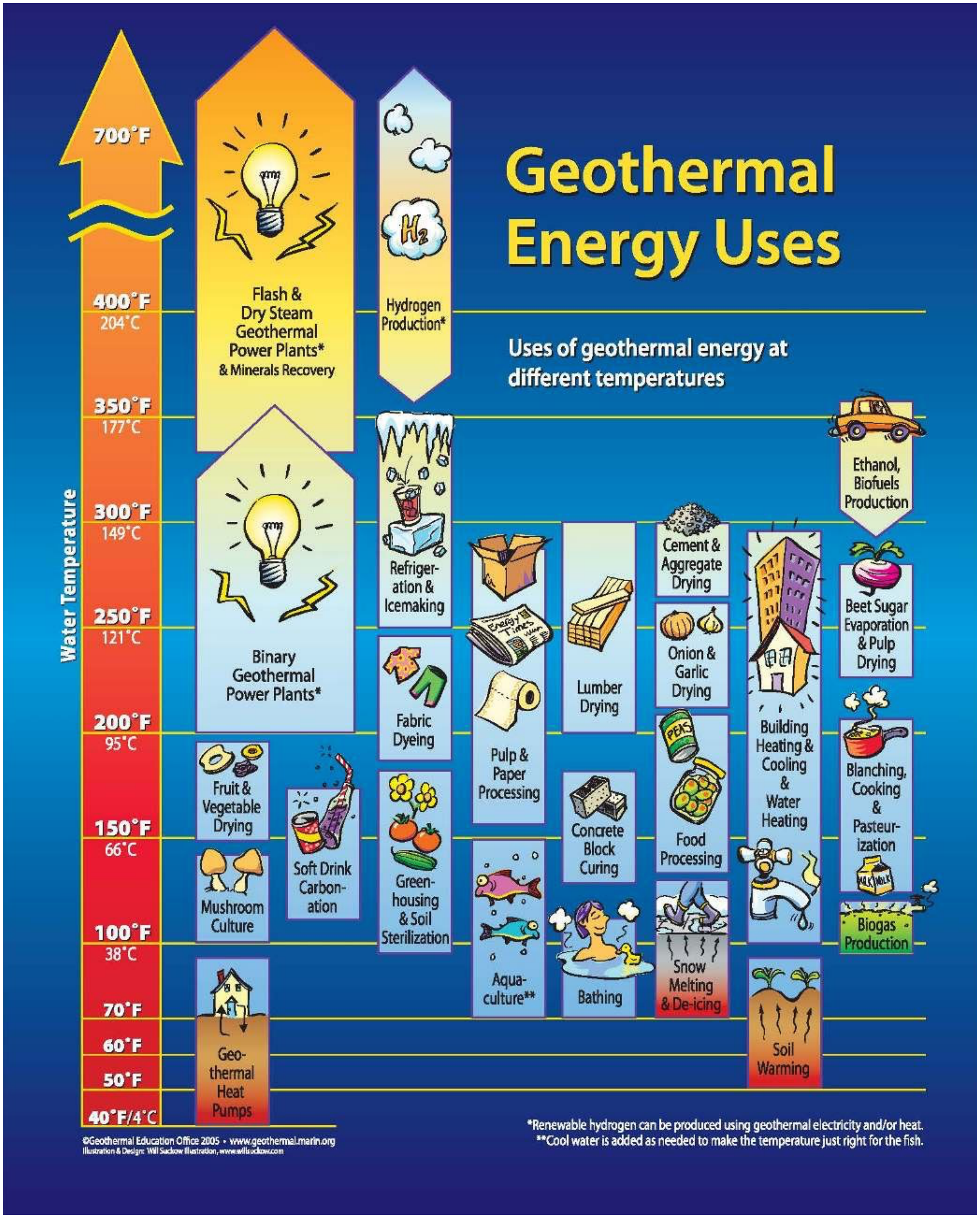
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000°C, for comparison, the temperature on the surface of the sun is approximately 5,500°C. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180ºC and above), medium (100-180ºC), and low (80-100ºC) temperature resources with fluids under 80ºC being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235ºC or above); flash plants (turning geothermal fluids of at least 150ºC into steam to drive a turbine); and binary power plants (using hot waters above 80ºC to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180ºC.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

---

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

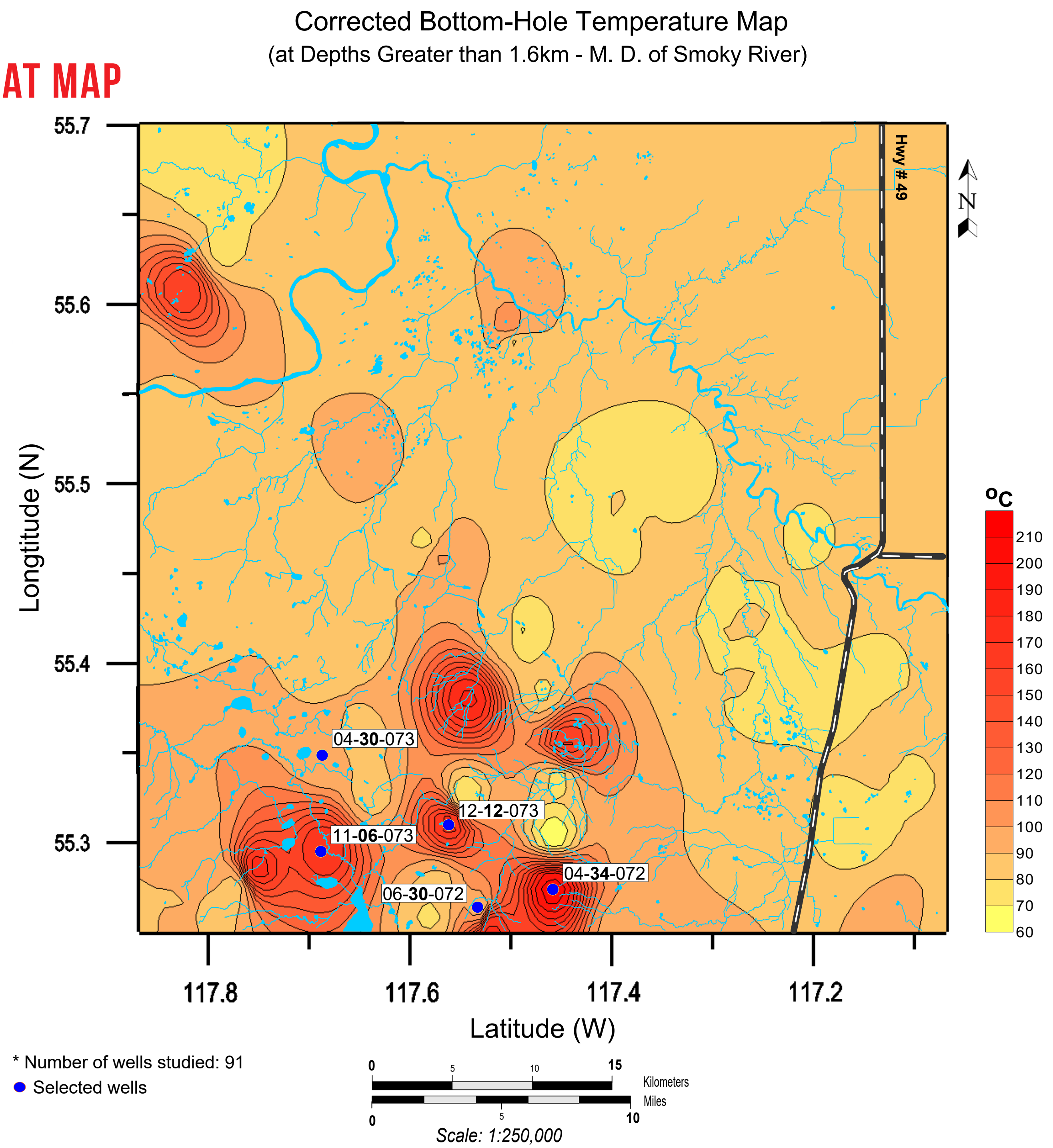
The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

RESEARCH RESULTS: M.D. OF SMOKY RIVER

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

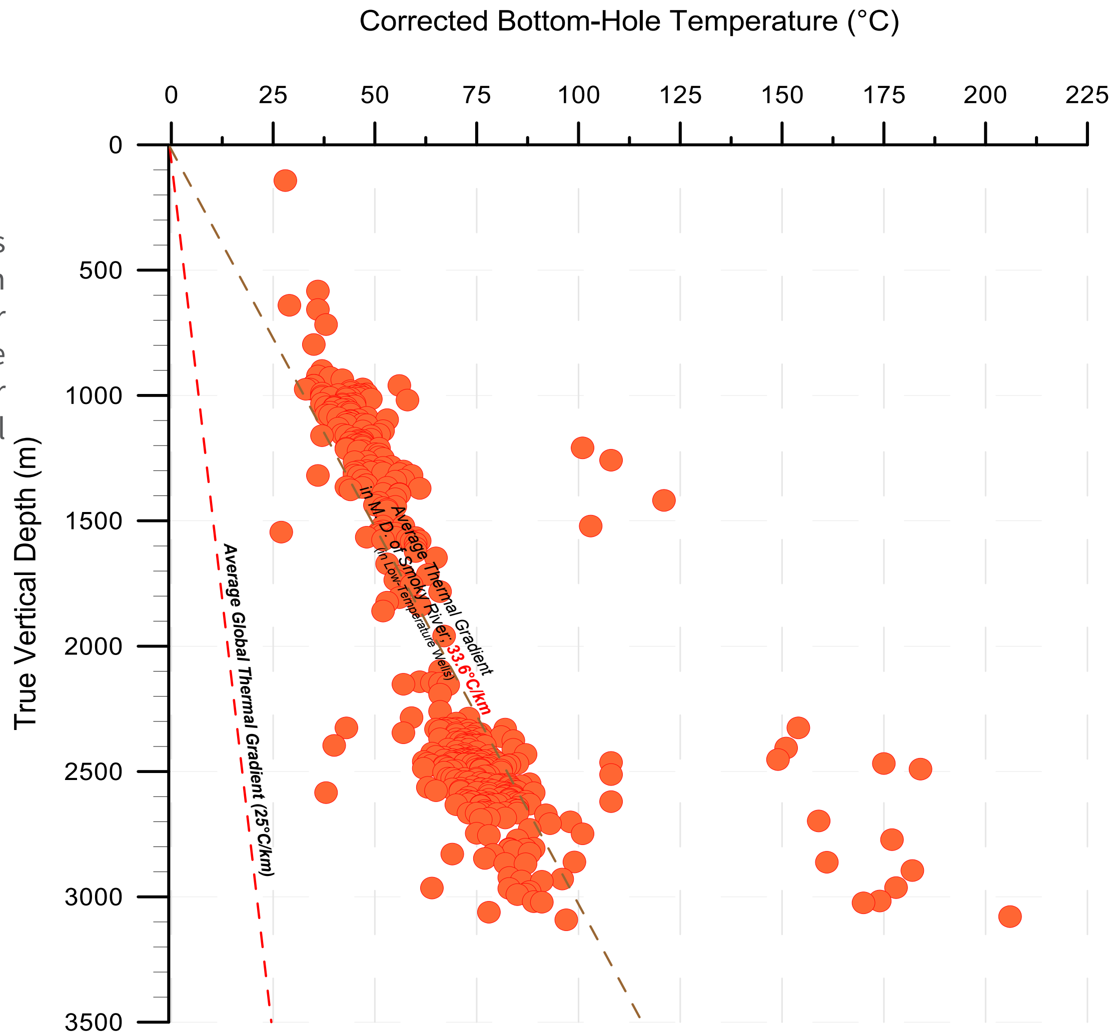
HEAT MAP



RESEARCH RESULTS: M.D. OF SMOKY RIVER

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 5 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Gillwood (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/04-34-072-23W5/00	3077.6	-61.3	206	220	177293 Cda Ltd
100/11-06-073-24W5/00	3022.7	-32.7	170	180	Mobil-Gc Cda Ltd
100/04-30-073-24W5/00	3020.2	-226.3	91	100	Paramount Rsrcs Ltd
100/06-30-072-23W5/00	3018	-9	89	100	Suncor Enrg Inc(2)
100/12-12-073-24W5/00	3015.4	-38.1	174	180	Phoenix Rsrcs Comp

KEY TAKEAWAYS

- The productive geothermal formations underlying the study area are the **Granite Wash** formation and the **Gilwood** member
- The geothermal gradient in your region is **33.6ºC/km.** This is **34% higher** than the global average.
- The identified temperatures indicate the possibility for **direct-use** activities in your region

RECOMMENDATION & NOTES

Our investigation of the geothermal potential of the M.D. of Smoky River has uncovered several beneficial and potentially detrimental factors to geothermal development. Excellent temperature readings registered in wells drilled to 2500m indicate the ability to support direct-use activities, and a cluster of wells show temperatures high enough to support power generation (not included in the temperature gradient calculation). Geologically, the Devonian strata underlying the study area has a thickness of 700m but the two identified geothermal formations are thin (37.2m thick). Therefore, the formations may be hot enough to support geothermal production but may not contain enough fluid. It is recommended that a further study be undertaken which encompass the entire M.D. in order to find locations with thicker productive formations and the ability to support sustained geothermal production.

September 25, 2018

Geothermal Analysis

Municipal District of Spirit River

Study by Terrapin Geothermics

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above 0^{o}C.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

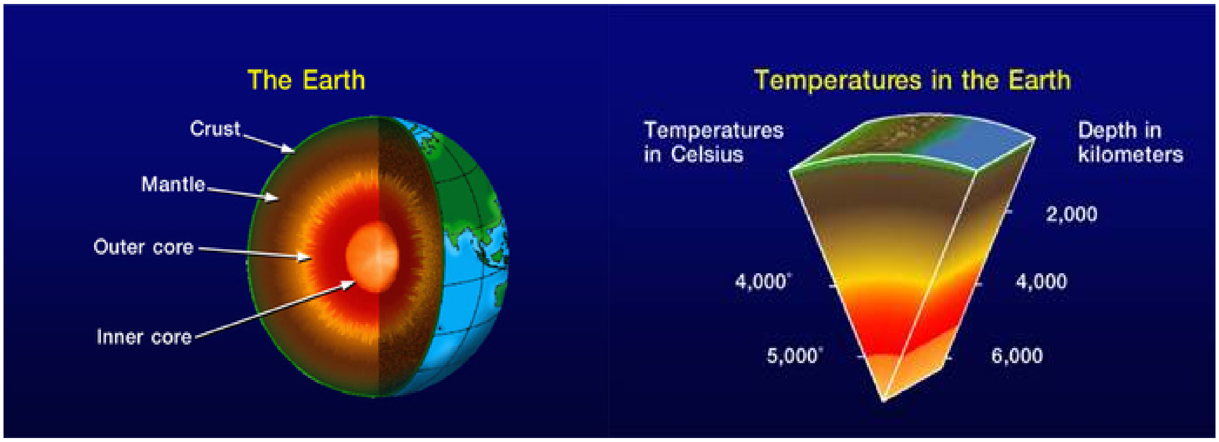
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

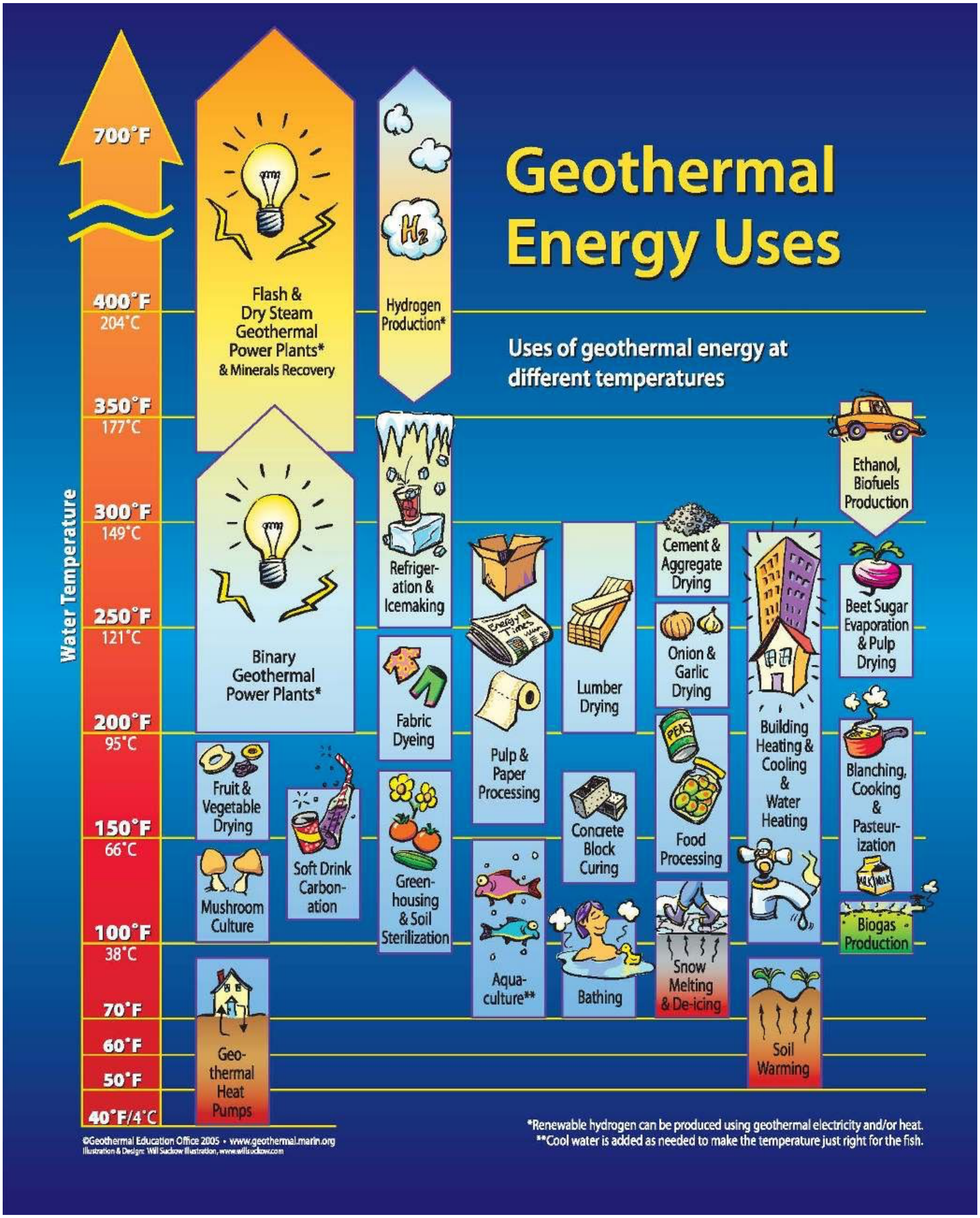
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160ºC and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180ºC and above), medium (100-180ºC), and low (80-100ºC) temperature resources with fluids under 80ºC being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235ºC or above); flash plants (turning geothermal fluids of at least 150ºC into steam to drive a turbine); and binary power plants (using hot waters above 80ºC to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180ºC.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

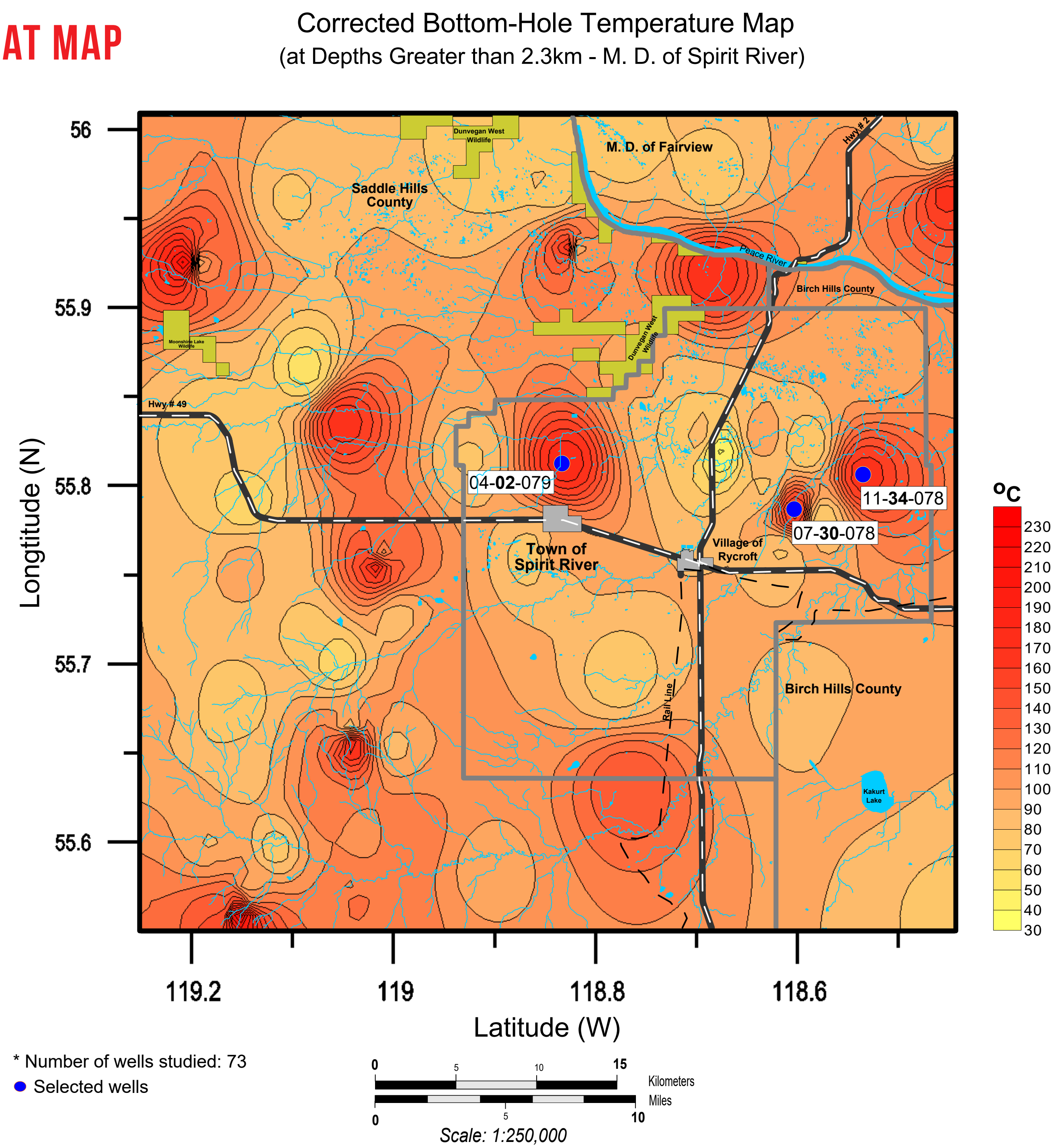
The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

RESEARCH RESULTS: M.D. OF SPIRIT RIVER

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

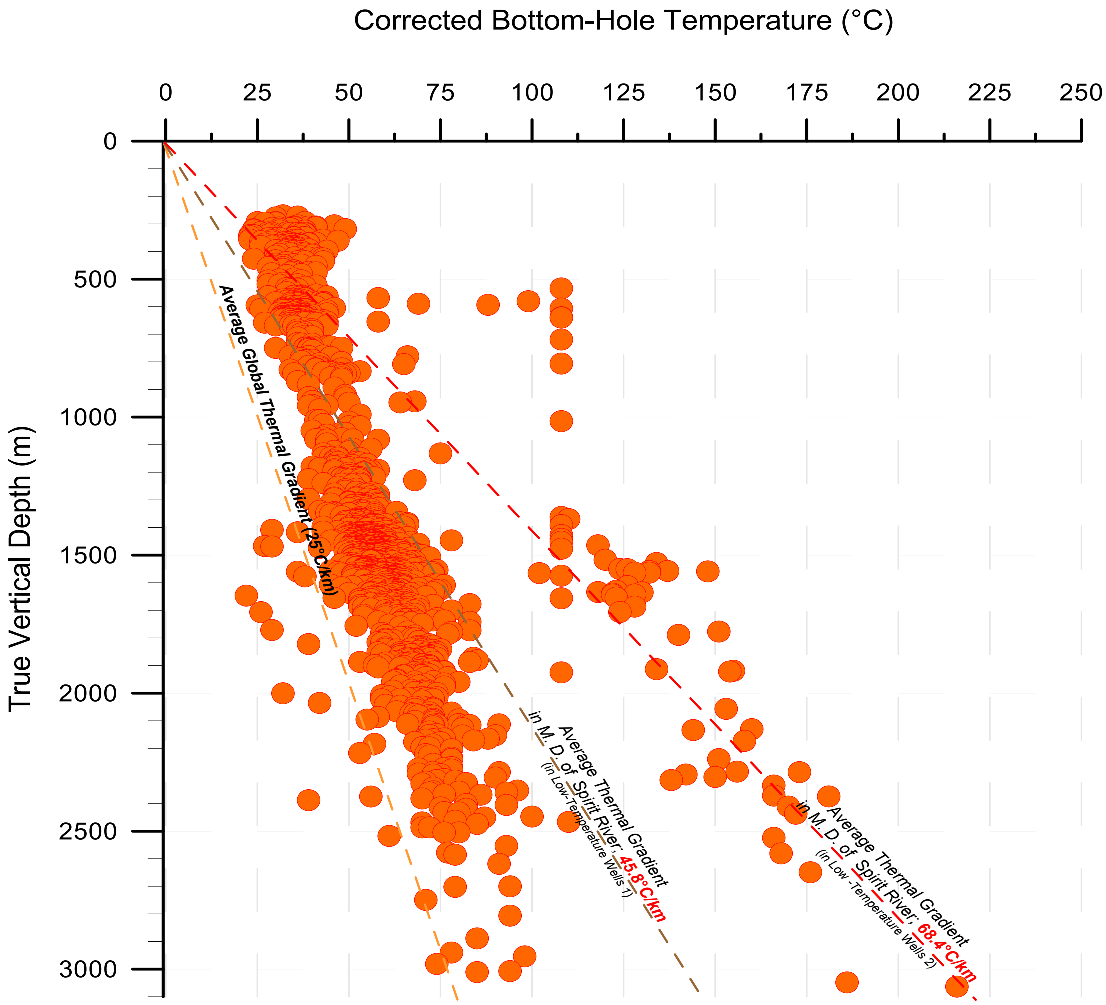
HEAT MAP



RESEARCH RESULTS: M.D. OF SPIRIT RIVER

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 3 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Granite Wash F. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/04-02-079-06W6/00	2647.8	-129.3	176	180	Repsol O&G Cda Inc
100/11-34-078-04W6/00	2523.1	-17.4	166	180	Repsol O&G Cda Inc
100/07-30-078-04W6/00	2579.5	-49.7	168	180	Chevron Cda Prop Lmtd

KEY TAKEAWAYS

- The identified productive geothermal formation in your area is the **Granite Wash** formation.
- There are two sets of temperature measurements in your area: a low-moderate grouping with a gradient of **45.8ºC/km** and a moderate-high grouping with a gradient of **68.4ºC/km**.
- There is potential for **geo-exchange** activities in the study area. Temperature readings are high enough to support **direct use** or **power generation** activities.

RECOMMENDATION & NOTES

Our study of the M.D. of Spirit River has uncovered both beneficial and detrimental factors to geothermal development. There are large number of wells with the temperatures necessary to support geothermal direct-use or power generation activity. However, the only recorded geothermal formation in the study area is extremely thin (6-12m) and may not be able to sustain large scale geothermal activities. Further studies into the potential of other local Devonian-aged formations to support geothermal activity is strongly recommended. In the interim, it is suggested that the M.D. of Spirit River investigate the opportunity to build geo-exchange systems to take advantage of the relatively stable temperature below the frostline.

September 25, 2018

Geothermal Analysis

Mackenzie County

Study by Terrapin Geothermics

For further information,
contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above 0^{o}C.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

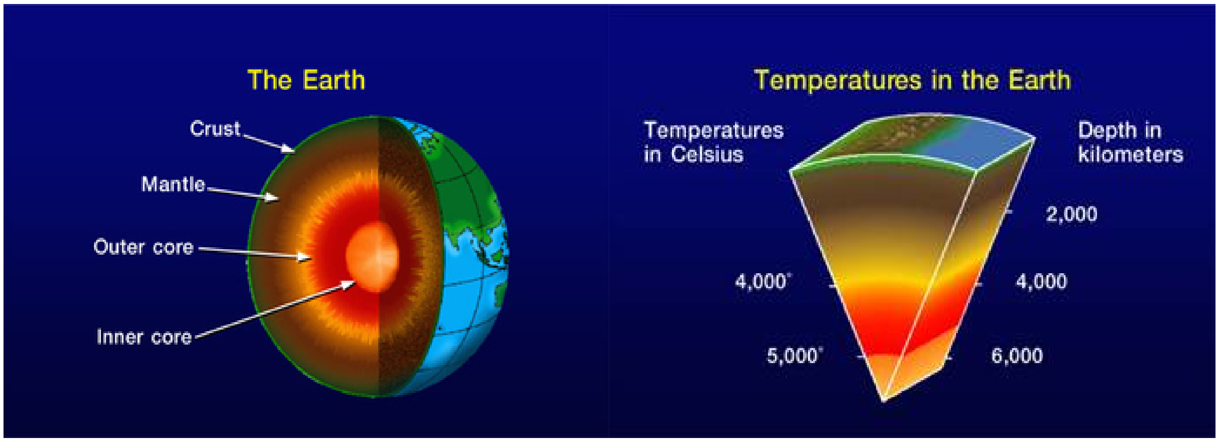
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

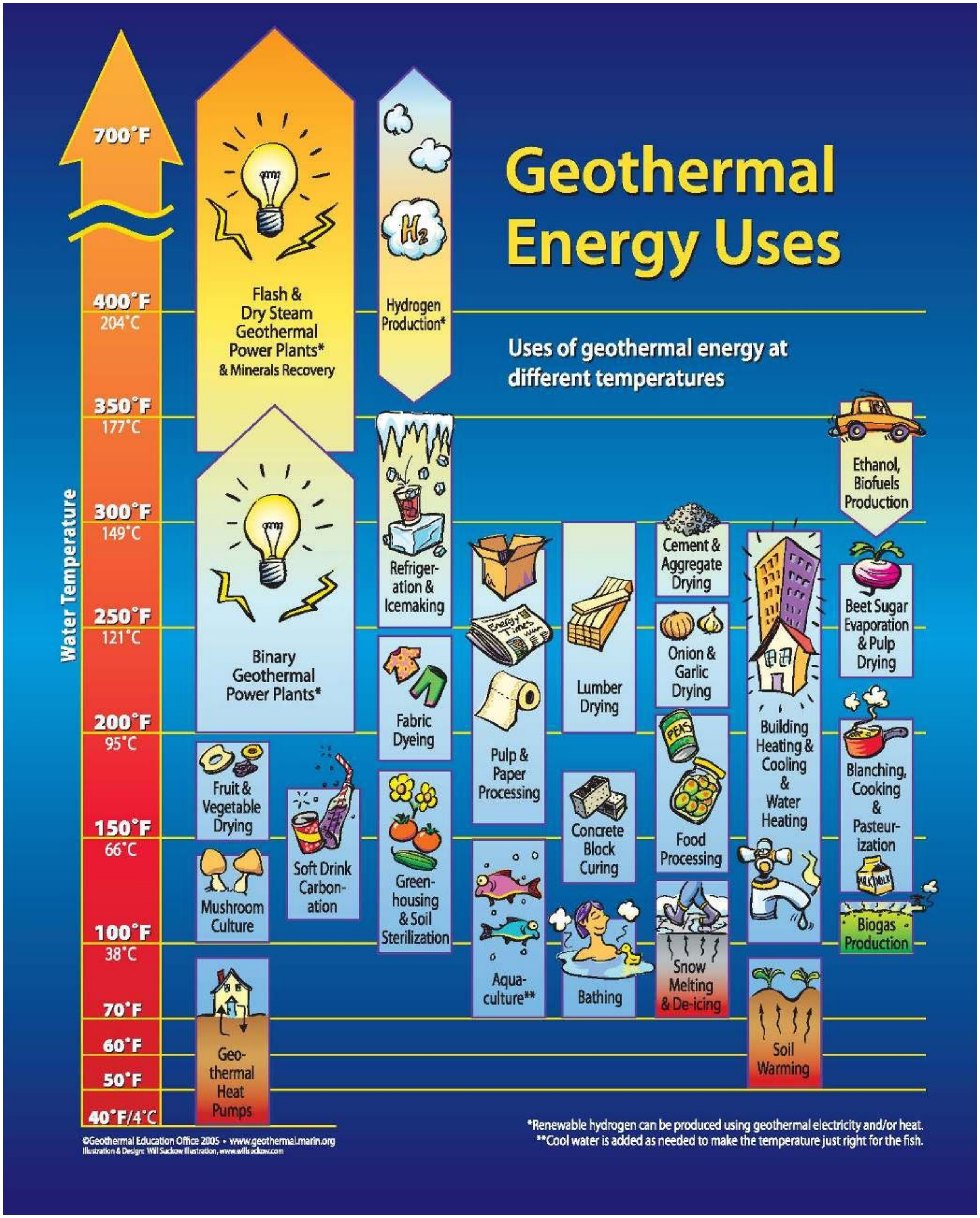
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180^{o}C and above), medium (100-180^{o}C), and low (80-100^{o}C) temperature resources with fluids under 80^{o}C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235^{o}C or above); flash plants (turning geothermal fluids of at least 150^{o}C into steam to drive a turbine); and binary power plants (using hot waters above 80^{o}C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180^{o}C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

---

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

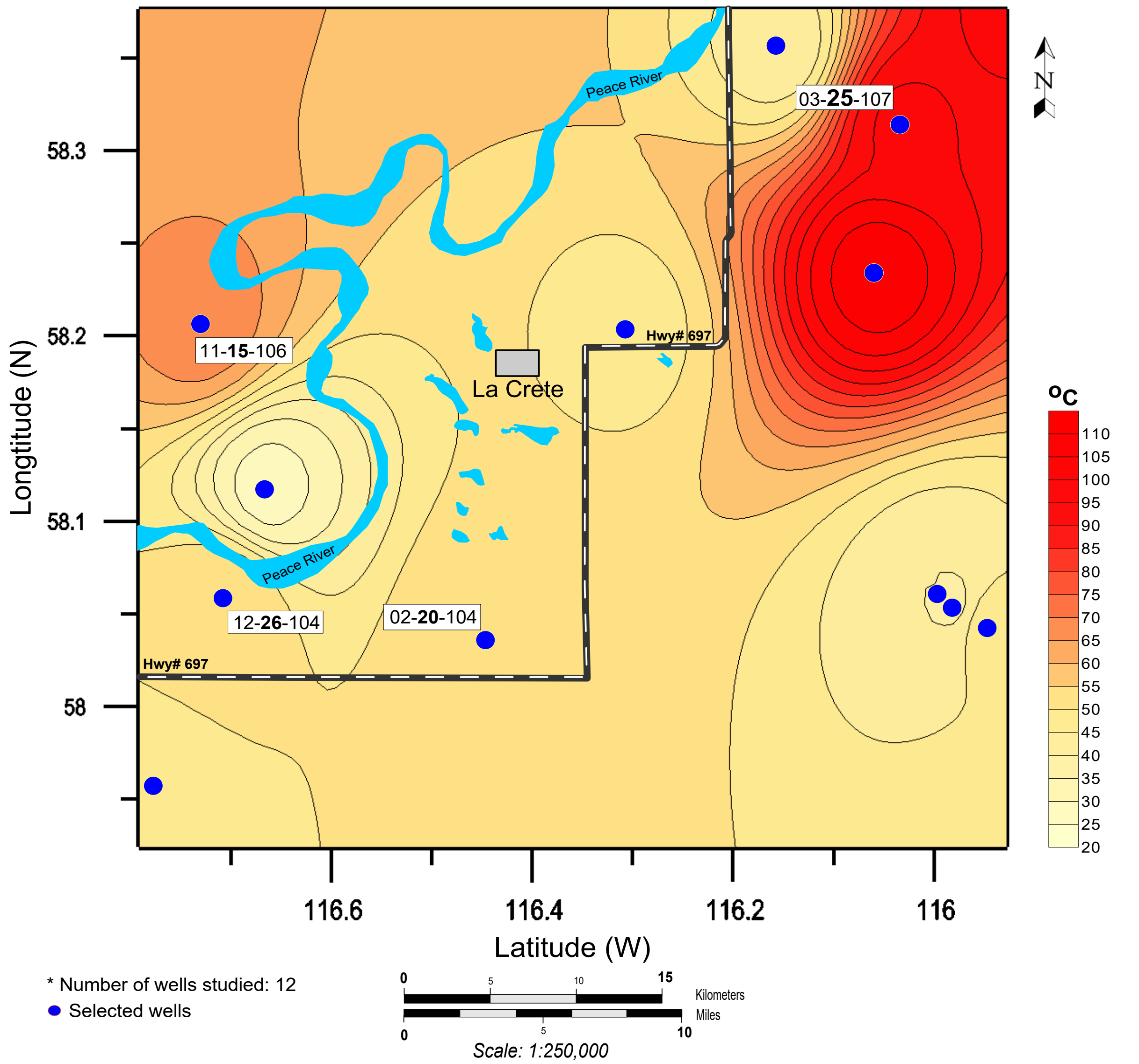
RESEARCH RESULTS: MACKENZIE COUNTY

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

HEAT MAP

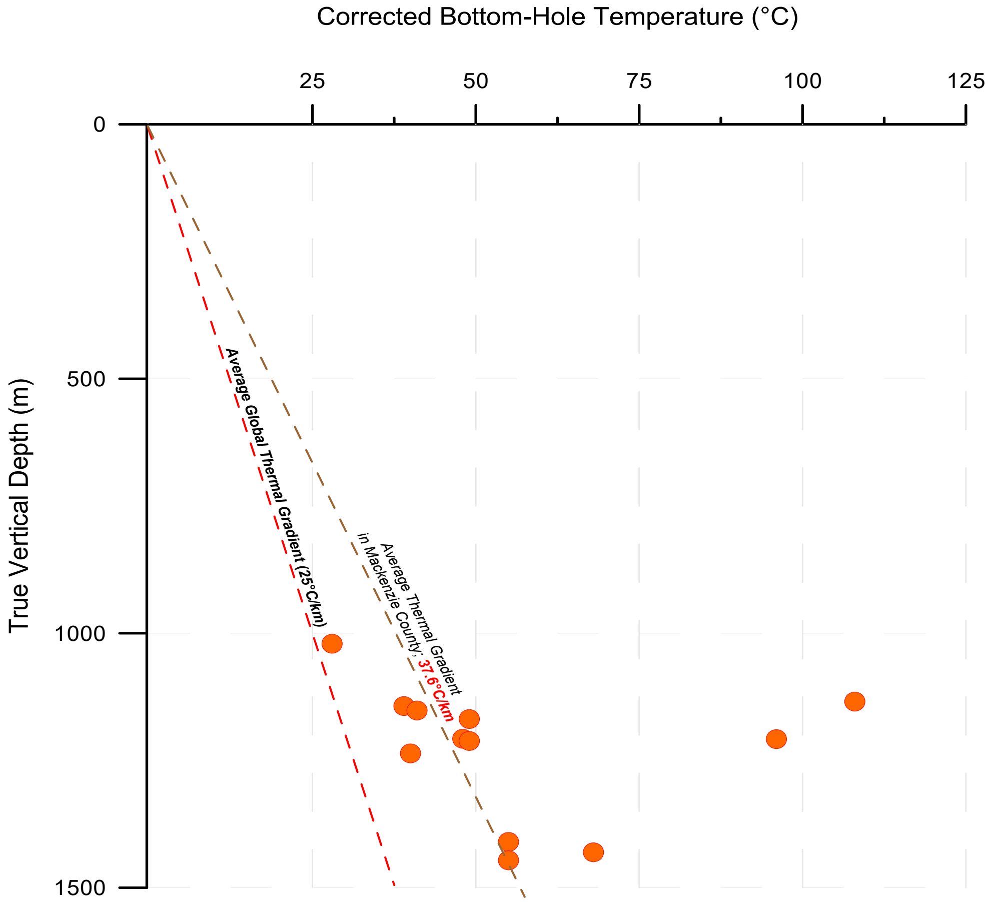
Corrected Bottom-Hole Temperature Map
(at Depths Greater than 1km - Mackenzie County)



RESEARCH RESULTS: MACKENZIE COUNTY

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 4 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Gilwood (m)	Corrected Bottom-Hole Temperature (°C)	Expected Temperature at Gilwood F. (°C)	Current Operator
100/03-25-107-13W5/00	1207.6	-399.3	96	100	BP Cda Enrg Grp ULC
100/11-15-106-17W5/00	1429.9	-420.7	68	70	Sunoma Enrg Corp
100/02-20-104-15W5/00	1409.5	-385.5	55	60	ConocoPhillips Cda Rsrcs
100/12-26-104-17W5/00	1445.7	-379.6	55	60	Sunoma Enrg Corp

KEY TAKEAWAYS

- The hottest geological formation in Mackenzie County is the **Gilwood Member**.
- The sedimentary formations in the study area are quite **shallow** with the bedrock being present at 1400m depth.
- The geothermal gradient in the study area was **37.6°C/km**. This is **50% higher** than the global average.
- There are high enough temperature readings to support **direct use applications** in the northeast of the study area.

RECOMMENDATION & NOTES

Our study of Mackenize County, focusing on La Crete and the surrounding area, has uncovered a number of factors that are detrimental to large-scale geothermal development. The only recorded geothermal formation in the study area is shallow and very thin (between 5 and 16m thick). These factors indicate that it is unlikely that the Gilwood Member could contain enough geothermal fluid to sustain any direct use activities. It is recommended that this study's scope be expanded to encompass the entirety of the County in order to identify areas with thicker sedimentary cover and better geothermal potential. In the interim, the County should investigate opportunity to build geo-exchange systems to take advantage of the relatively stable temperature below the frostline.

September 25, 2018

Geothermal Analysis

Northern Sunrise County

Study by Terrapin Geothermics

For further information,
contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

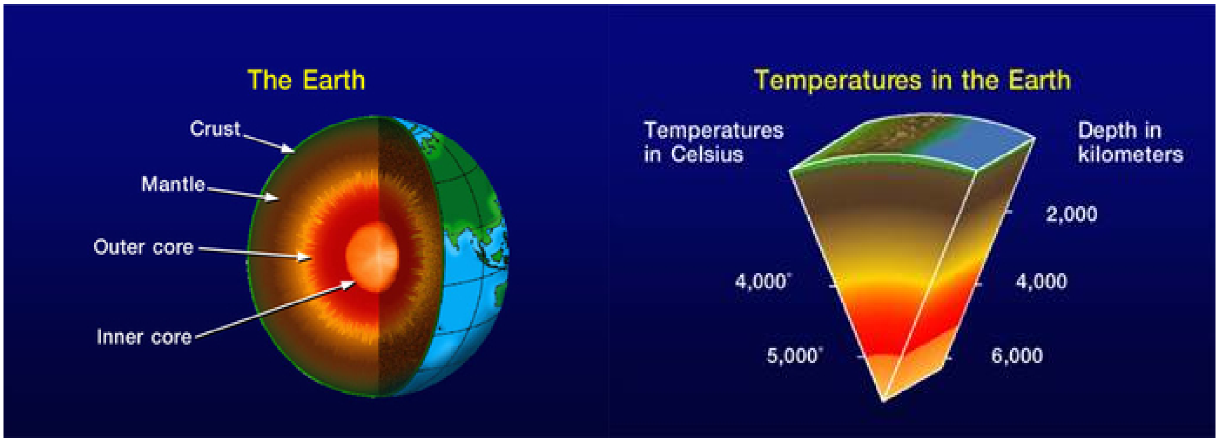
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

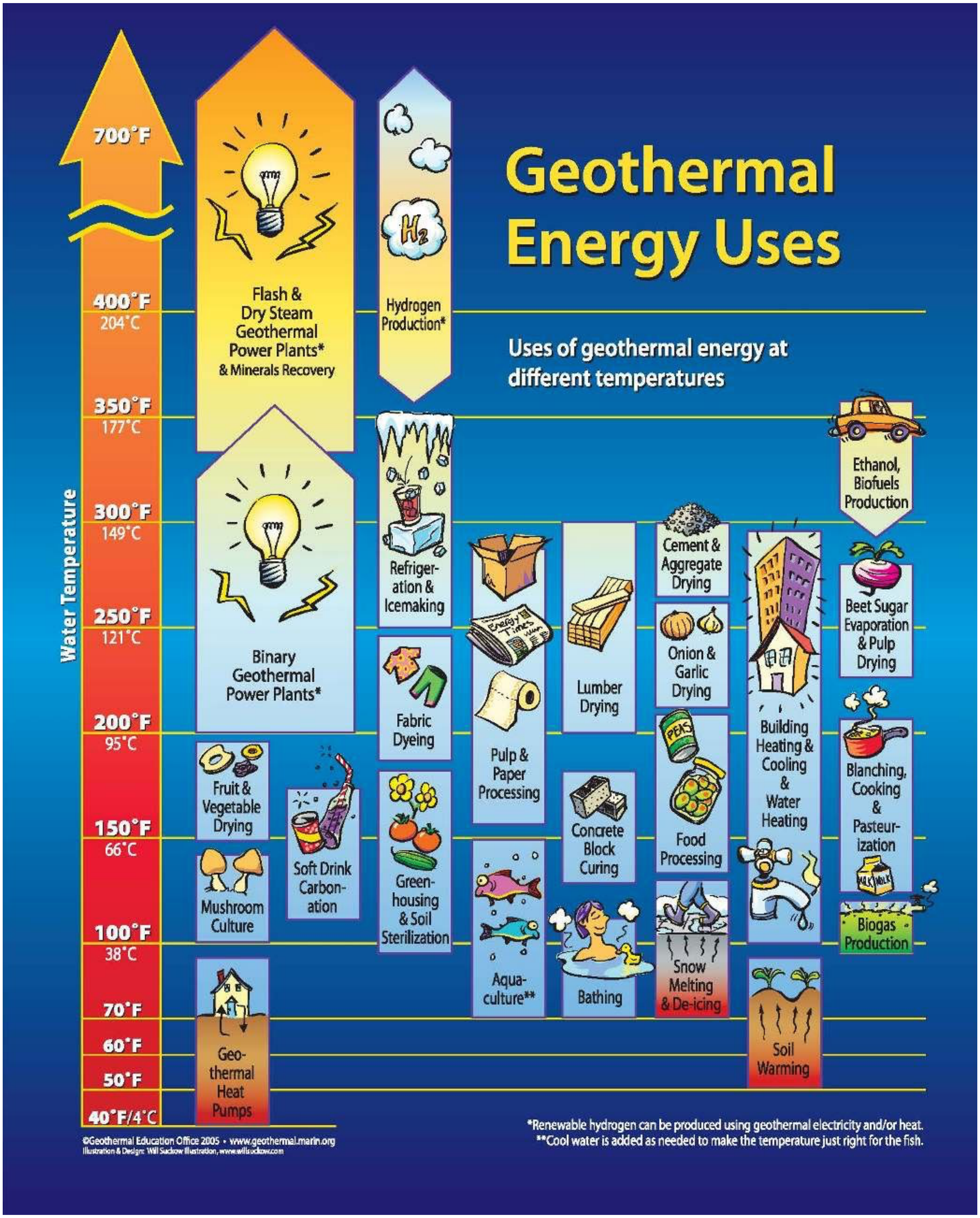
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180°C and above), medium (100-180°C), and low (80-100°C) temperature resources with fluids under 80°C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235°C or above); flash plants (turning geothermal fluids of at least 150°C into steam to drive a turbine); and binary power plants (using hot waters above 80°C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180°C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

RESEARCH RESULTS:

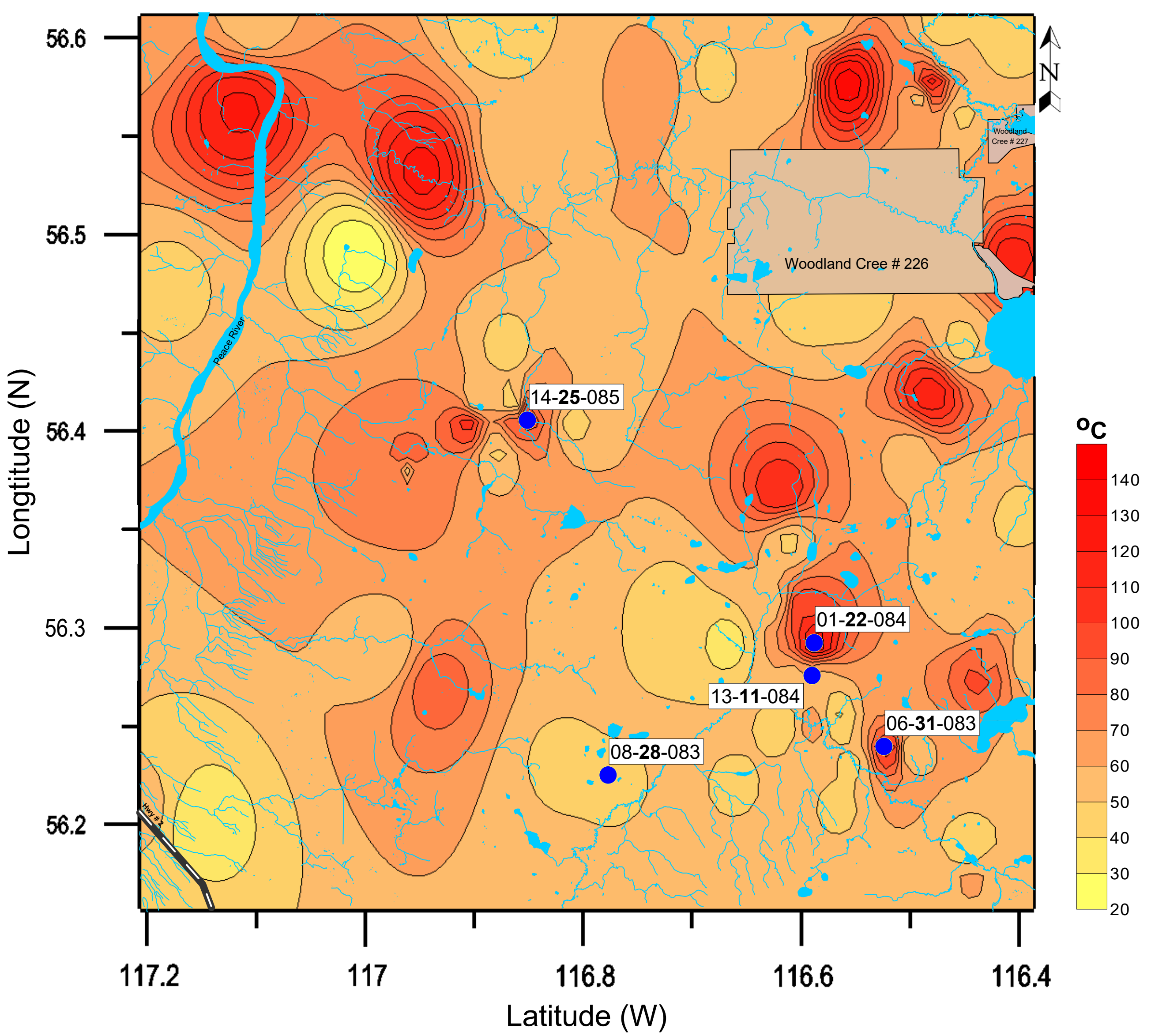
NORTHERN SUNRISE COUNTY

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

HEAT MAP

Corrected Bottom-Hole Temperature Map
(at Depths Greater than 1.5km - Northern Sunrise County)



* Number of wells studied: 80
Selected wells

Kilometers 0 5 10 15
Miles 0 5 10
Scale: 1:250,000

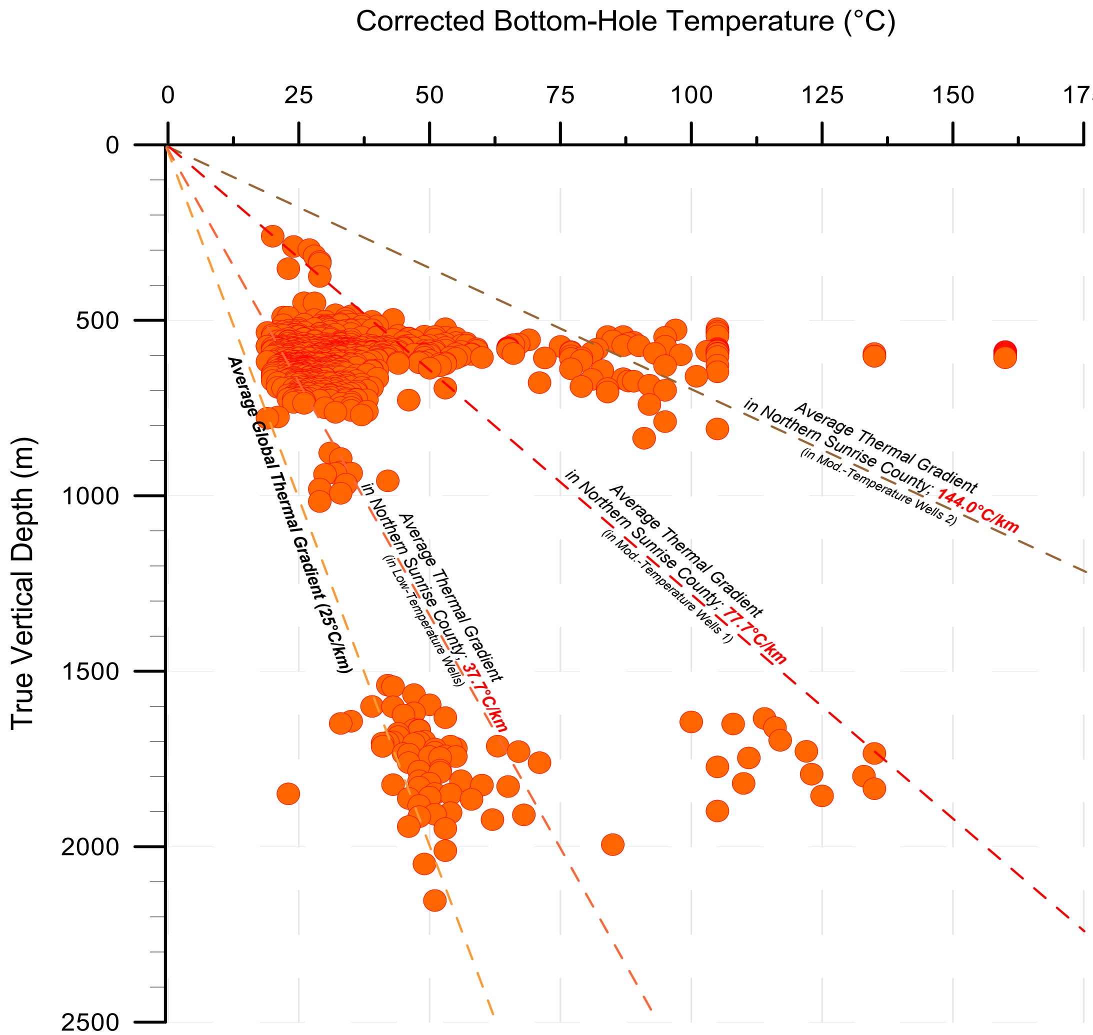
terrapin

RESEARCH RESULTS:

NORTHERN SUNRISE COUNTY

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 5 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Leduc F. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/14-25-085-19W5/00	1834	-315.4	135	140	BP Cda Enrg Grp ULC
100/01-22-084-17W5/00	1854.4	-303.6	125	140	Suncor Enrg Inc(2)
100/06-31-083-16W5/00	1897.4	-89.1	105	120	Mount Bastion O&G Corp
100/08-28-083-18W5/00	2048.4	-320.5	49	100	Inter-City Gas Corp
100/13-11-084-17W5/00	2152.6	-556.8	51	100	Devon Cda Corp

KEY TAKEAWAYS

- The two identified geothermal formations in your area are the **Leduc** and **Granite Wash** formations
- There are 4 clusters of temperature readings in the study area leading to indicated geothermal gradients of **37.7°C/km, 77.7°C/km**, and **144°C/km**. These are all higher than the global average.
- There is strong potential for **direct-use** activities in your region

RECOMMENDATION & NOTES

The thickness of the productive formations in the study area is good (322m average), likely to contain enough fluid to support geothermal production. The temperature readings in the study area, however, do not provide any answers. There are 4 clusters of temperature readings (2 at 500-750m depth and 2 at 1500-2000m depth). It is recommended that the County conducts an additional investigation which expands the scope of this study to encompass the entire County and also investigates these temperature clusters. This investigation would focus on identifying: any localized geological formations, the company that took the measurements, the temperature measurement tools utilized, and the year of the measurements. This should provide a more accurate picture of the resource potential underlying the study area and direct future development activity.

September 25, 2018

Geothermal Analysis

Peavine Metis Settlement

Study by Terrapin Geothermics

terrapin

For further information,
contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

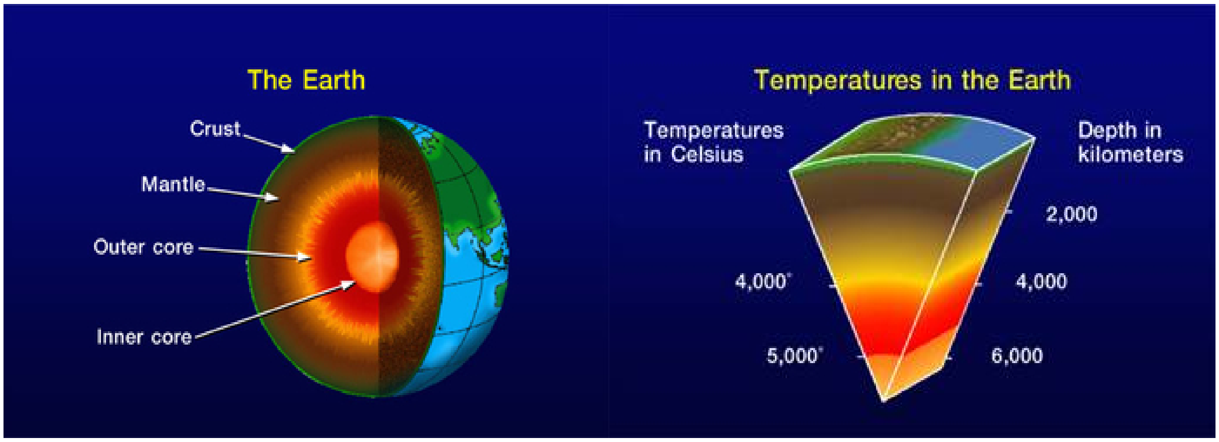
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

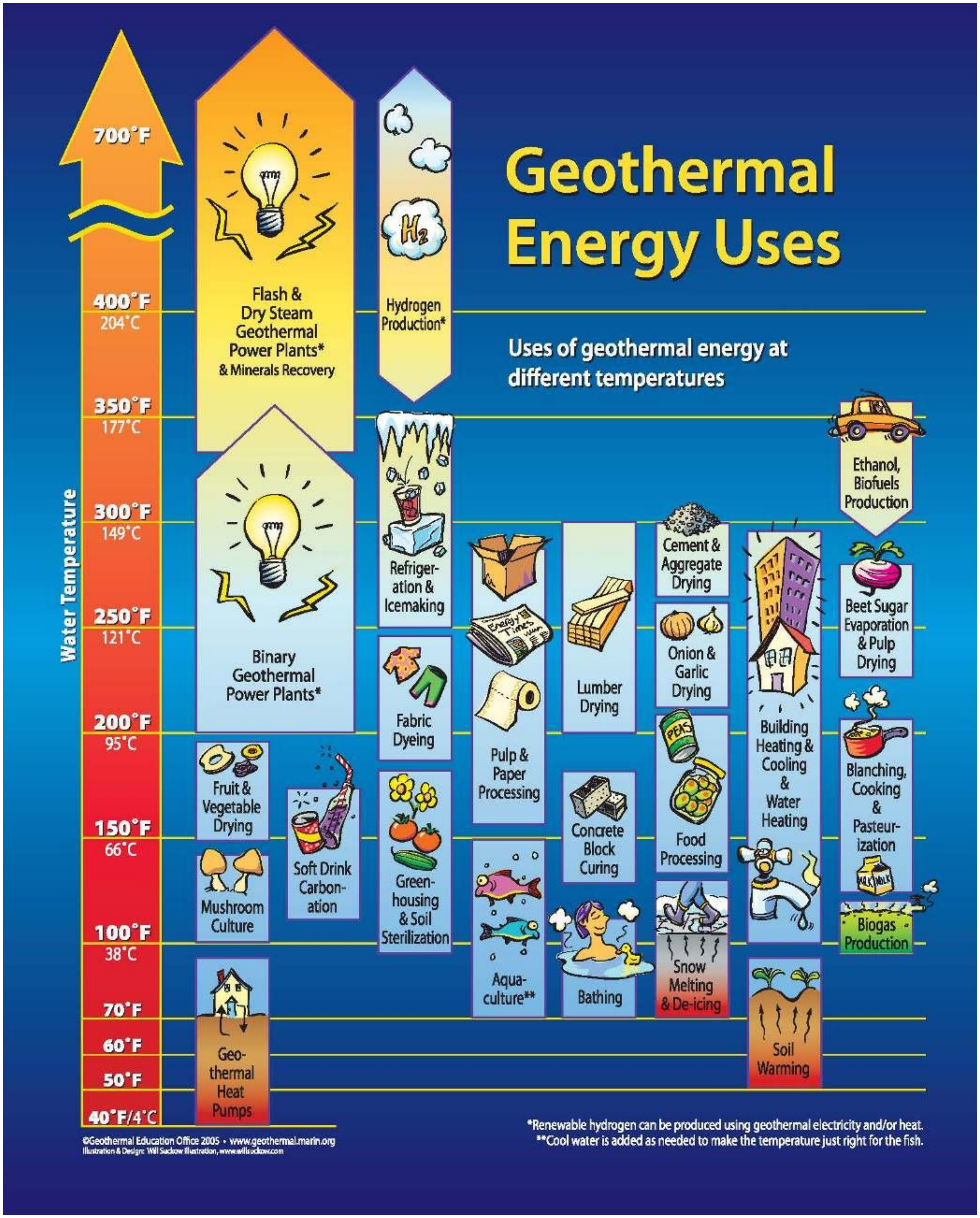
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160ºC and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180^{o}C and above), medium (100-180^{o}C), and low (80-100^{o}C) temperature resources with fluids under 80^{o}C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235^{o}C or above); flash plants (turning geothermal fluids of at least 150^{o}C into steam to drive a turbine); and binary power plants (using hot waters above 80^{o}C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180^{o}C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

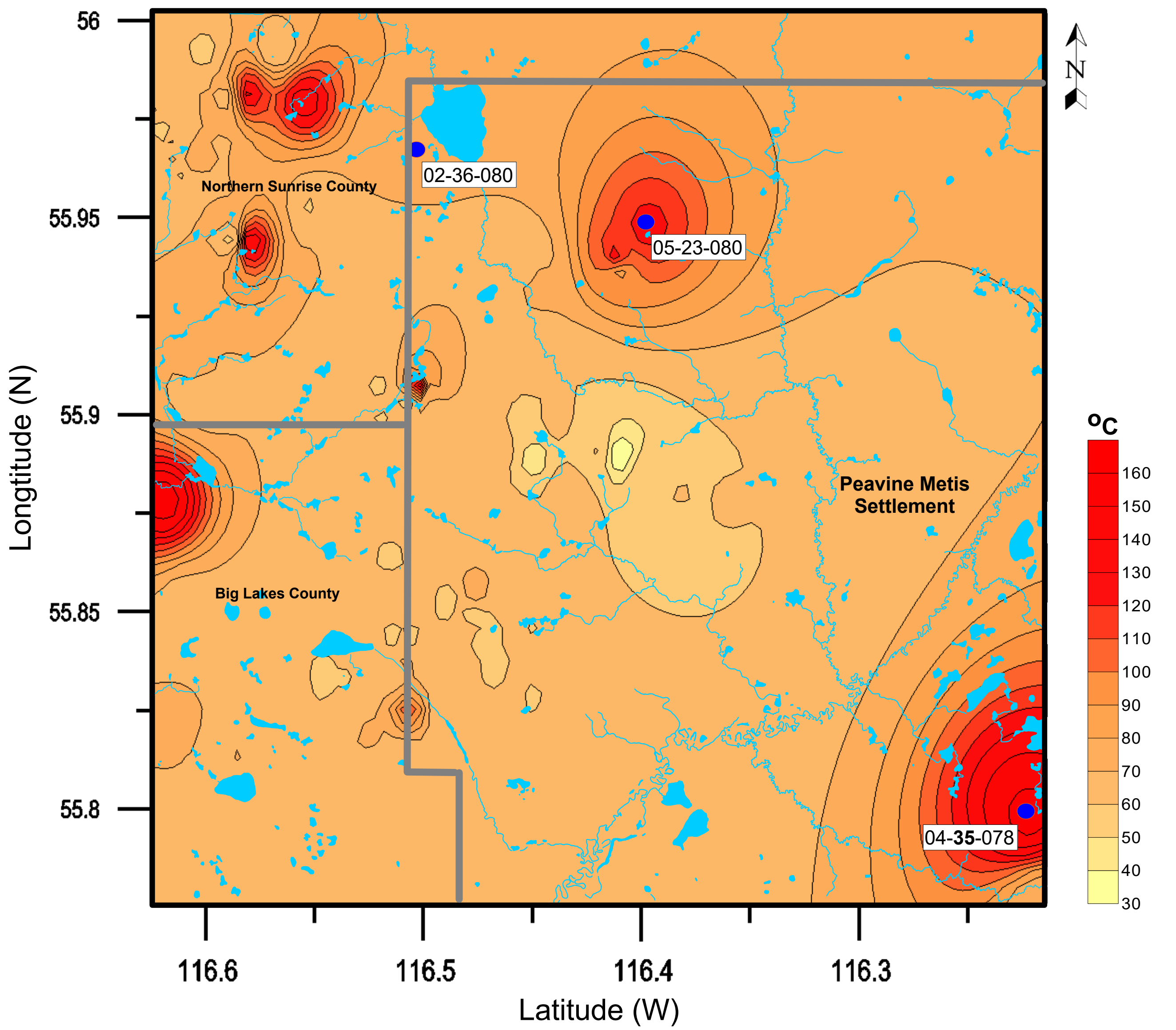
RESEARCH RESULTS:
PEAVINE METIS SETTLEMENT

CONTEXT

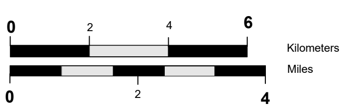
Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

HEAT MAP

Corrected Bottom-Hole Temperature Map
(at Depths Greater than 2.5km - eastern Peavine Metis Settlement)



* Number of well studied: 123
• Data points (wells)
● Selected wells



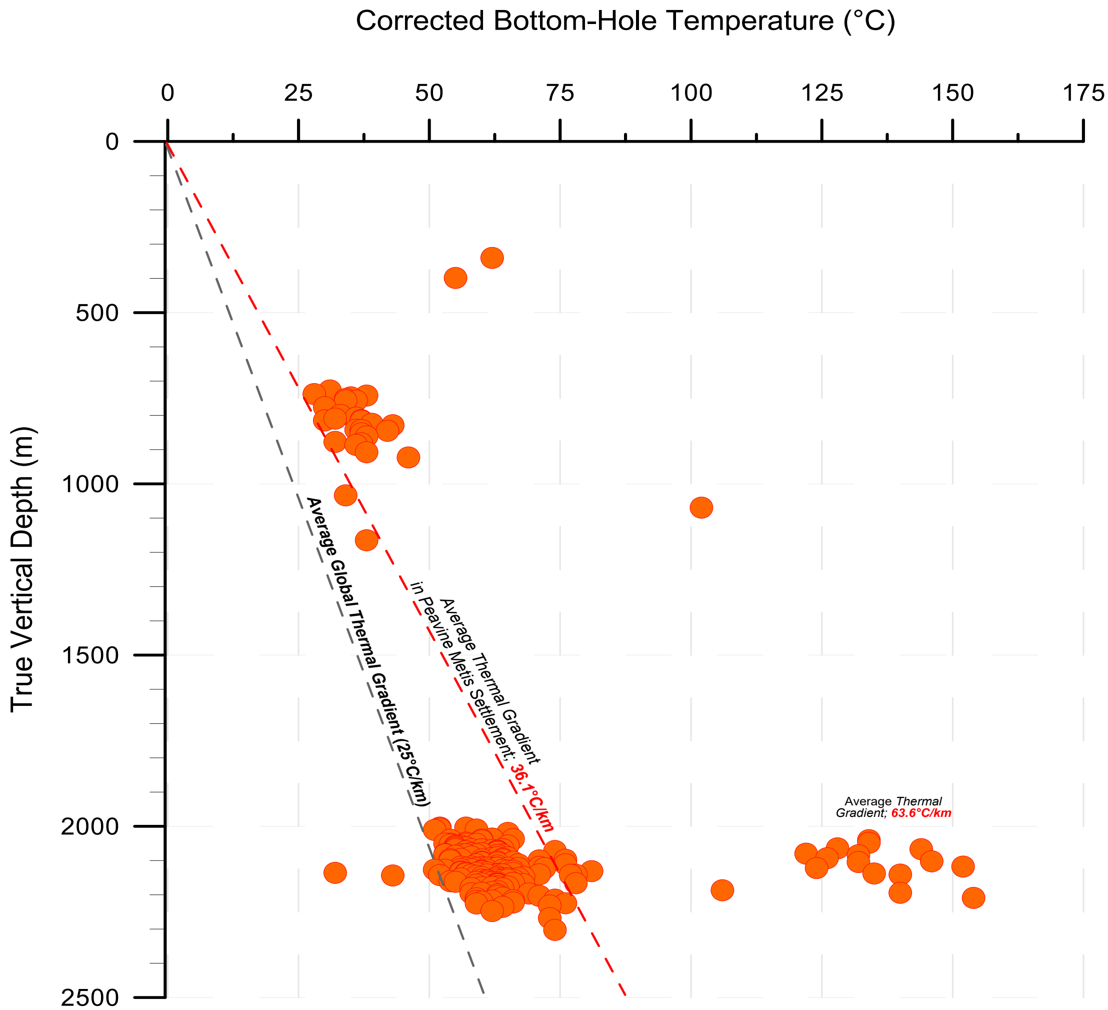
Scale: 1:150,000

RESEARCH RESULTS:

PEAVINE METIS SETTLEMENT

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 3 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Granite Wash F. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/04-35-078-15W5/00	2116.8	-9.8	152	160	Wainoco Oil Ltd(2)
100/02-36-080-17W5/00	2301.7	-268.9	74	120	Houston O&G Ltd(2)
100/05-23-080-16W5/00	2121.1	-14.7	124	140	Union Oil Comp of Cal

KEY TAKEAWAYS

- The identified productive geothermal formation in your area is the **Granite Wash** formation.
- There are two sets of temperature measurements in your area: a low-moderate grouping with a gradient of **36.1ºC/km** and a moderate-high grouping with a gradient of **63.6ºC/km**.
- There is potential for **geo-exchange** activities in the study area

RECOMMENDATION & NOTES

Our study of the Peavine Metis Settlement has uncovered both beneficial and detrimental factors to geothermal development. There are a number of wells with the temperatures necessary to support geothermal activity. However, the cluster of higher-temperature wells may not be indicative of the true temperature of the formation and require further investigation to validate. Also, the only recorded geothermal formation in the study area is quite thin (6m-35m) and may not be able to sustain any direct use activities. It is recommended that the Peavine Metis Settlement investigate the opportunity to build geo-exchange systems to take advantage of the relatively stable temperature below the frostline.

June 25, 2018

Geothermal Analysis

Regional Municipality of Wood Buffalo

Study by Terrapin Geothermics

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above 0^{o}C.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

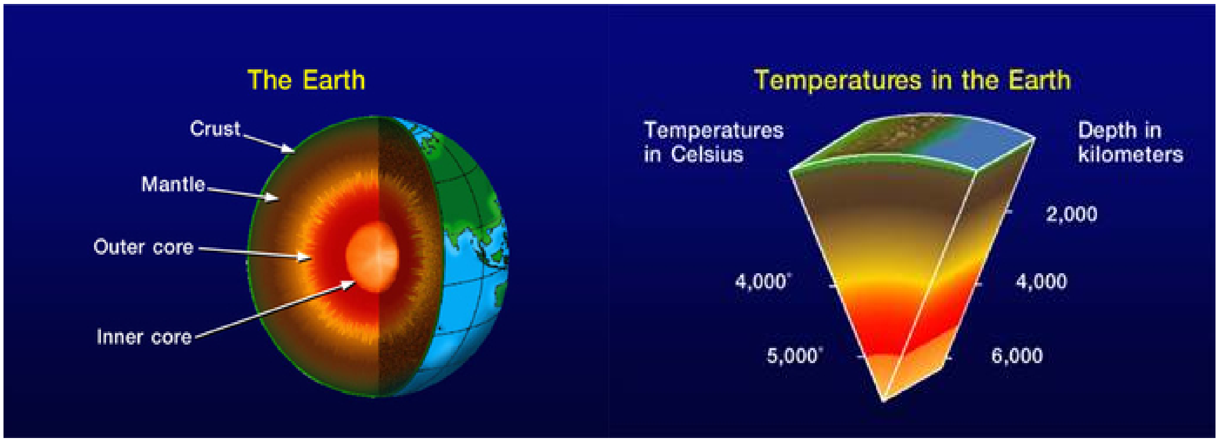
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

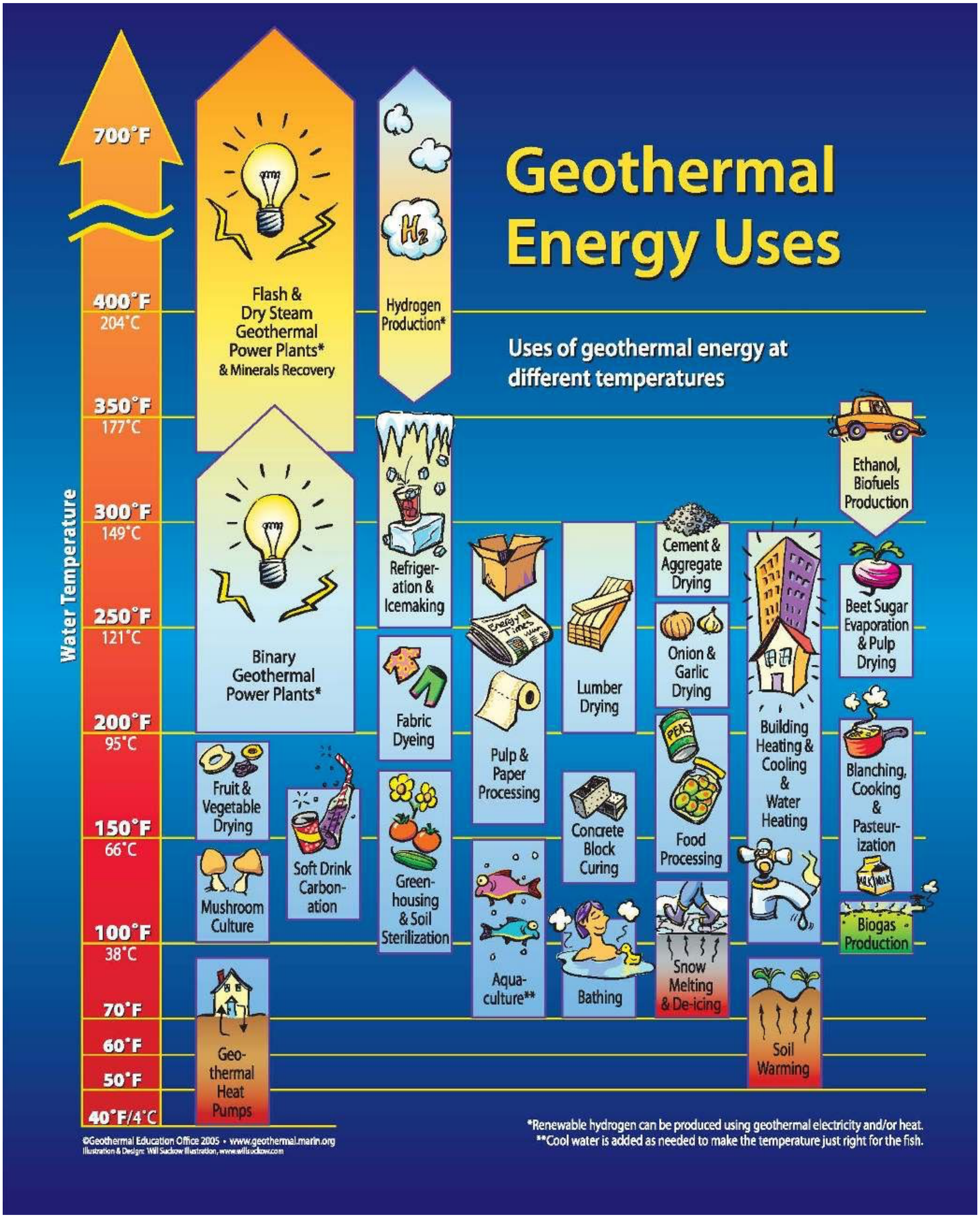
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180^{o}C and above), medium (100-180^{o}C), and low (80-100^{o}C) temperature resources with fluids under 80^{o}C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235^{o}C or above); flash plants (turning geothermal fluids of at least 150^{o}C into steam to drive a turbine); and binary power plants (using hot waters above 80^{o}C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180^{o}C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

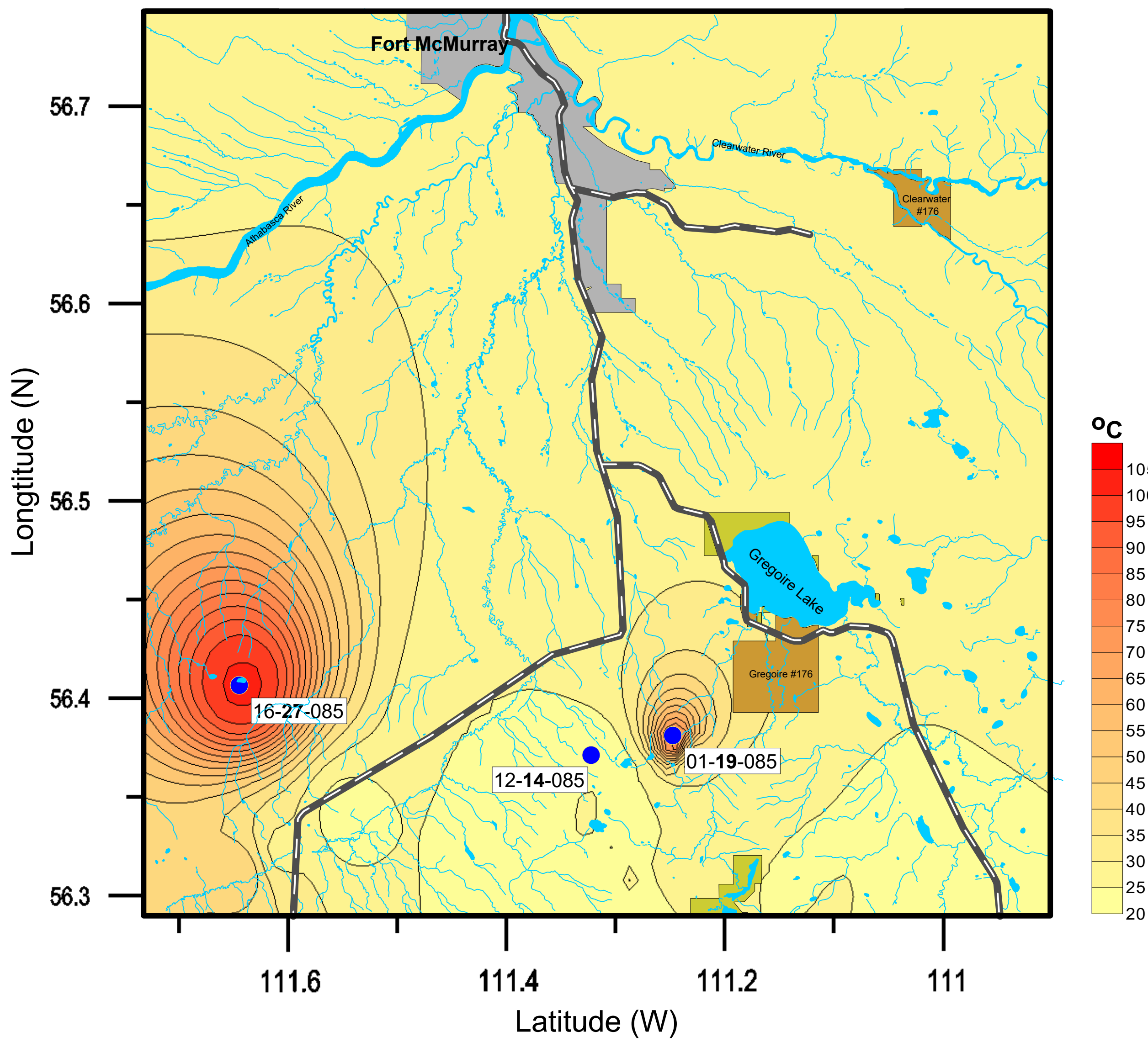
RESEARCH RESULTS: R.M. OF WOOD BUFFALO

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

HEAT MAP

Corrected Bottom-Hole Temperature Map
(at Depths Greater than 0.5km - Wood Buffalo)



* Number of wells studied: 51

● Selected wells

0 5 10 15 Kilometers

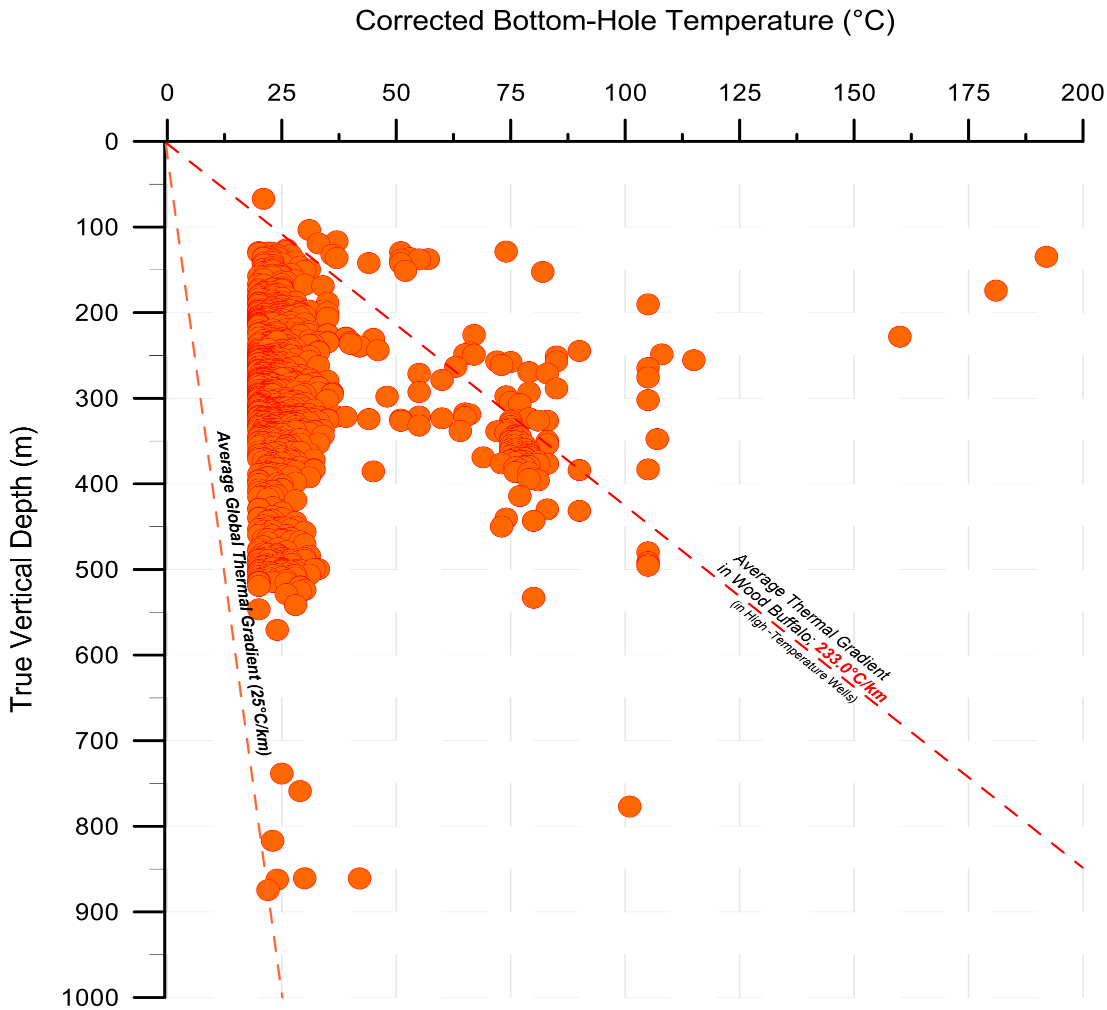
0 5 10 Miles

Scale: 1:250,000

RESEARCH RESULTS: R.M. OF WOOD BUFFALO

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 3 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Granite Wash F. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/16-27-085-11W4/00	776.6	-69.2	101	120	Imperial Oil Rsrcs Ltd(2)
1AA/01-19-085-08W4/00	532.7	312.5	80	100	Cdn Nat Rsrcs Ltd
100/12-14-085-09W4/00	874.2	-29.7	22	80	Suncor Enrg Inc(2)

KEY TAKEAWAYS

- The identified productive geothermal formation in your area is the **Granite Wash** formation.
- The indicated temperature gradient in the study area is **233ºC/km**. That is influenced by the shallowness of the wells in the area.
- There is potential for **geo-exchange** activities in the study area

RECOMMENDATION & NOTES

Our study of the R.M. of Wood Buffalo has uncovered factors that are detrimental to geothermal development. The only recorded geothermal formation in the study area is extremely thin (3.6m). This thinness makes it unlikely that the formation could contain enough geothermal fluid to sustain any direct use activities. As well, most wells in the region are extremely shallow and their temperature readings come from less than 600m depth. This lack of drilled depth compounds potentially anomalous results, improper measurement gathering, or data entry errors and can lead to a severe overestimation of the temperature potential. It is recommended that Wood Buffalo investigate the opportunity to build geo-exchange systems to take advantage of the relatively stable temperature below the frost-line, or attempts to understand temperature anomalies through further research.

September 25, 2018

Geothermal Analysis

Saddle Hills County

Study by Terrapin Geothermics

For further information,
contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above 0^{o}C.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.

Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.

More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

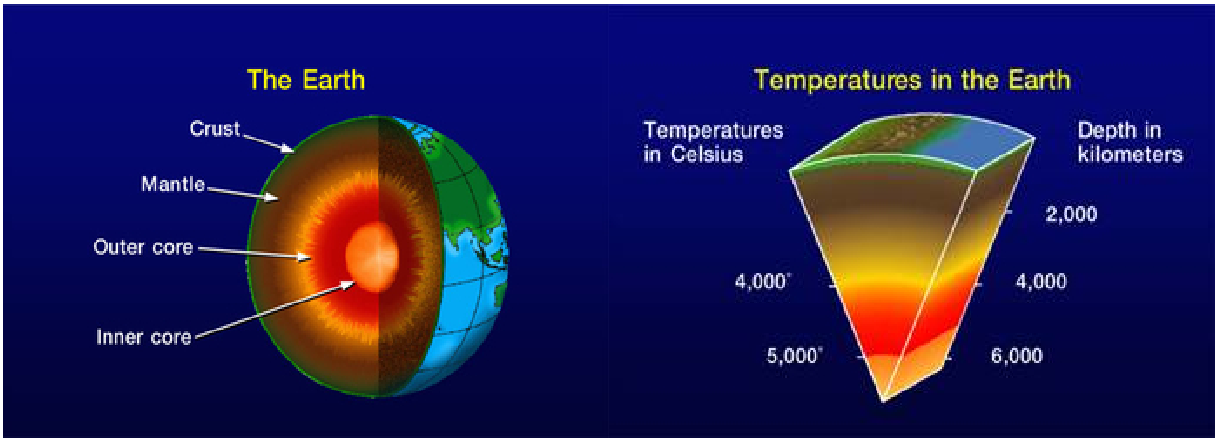
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

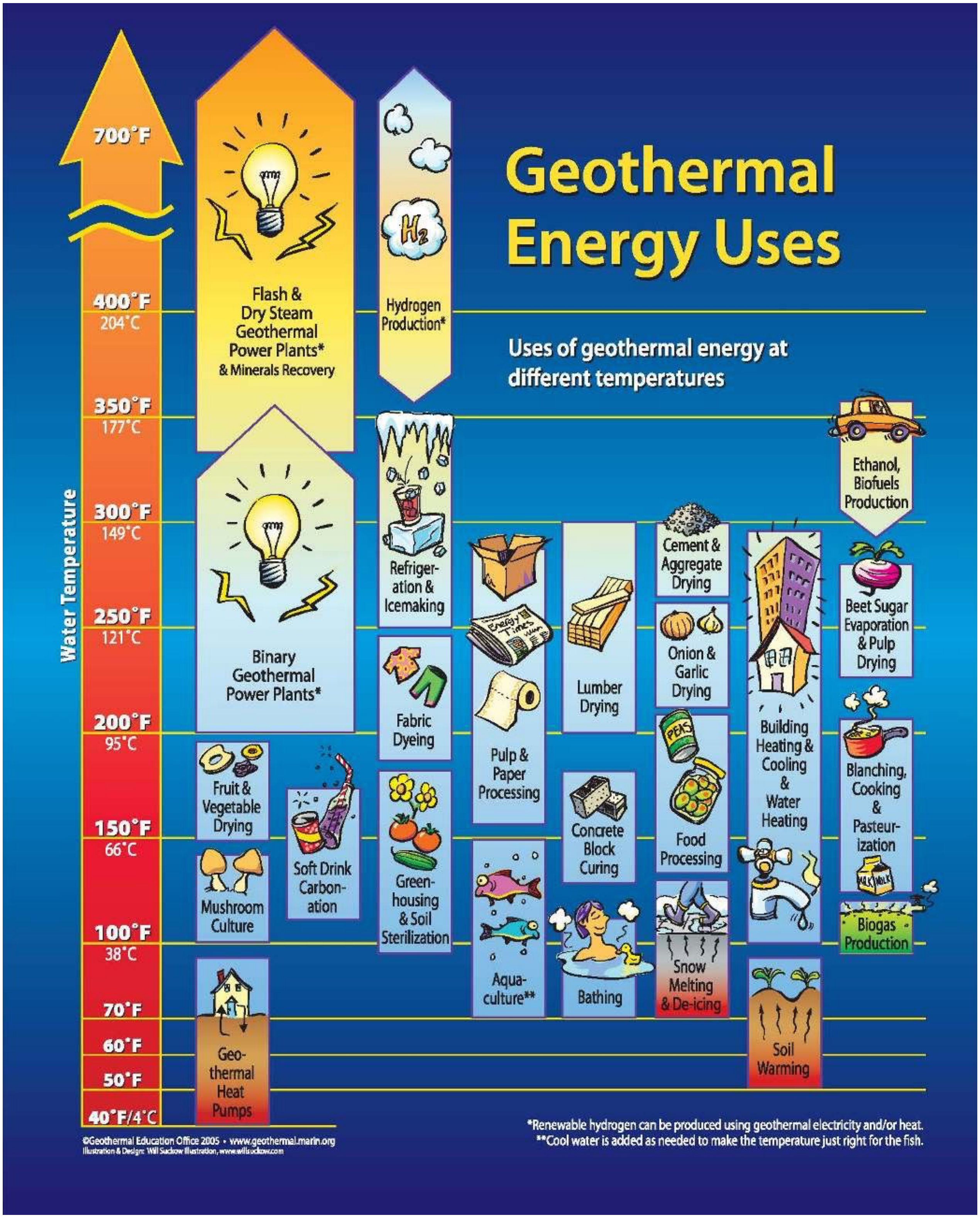
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160^{o}C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180^{o}C and above), medium (100-180^{o}C), and low (80-100^{o}C) temperature resources with fluids under 80^{o}C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235^{o}C or above); flash plants (turning geothermal fluids of at least 150^{o}C into steam to drive a turbine); and binary power plants (using hot waters above 80^{o}C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180^{o}C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

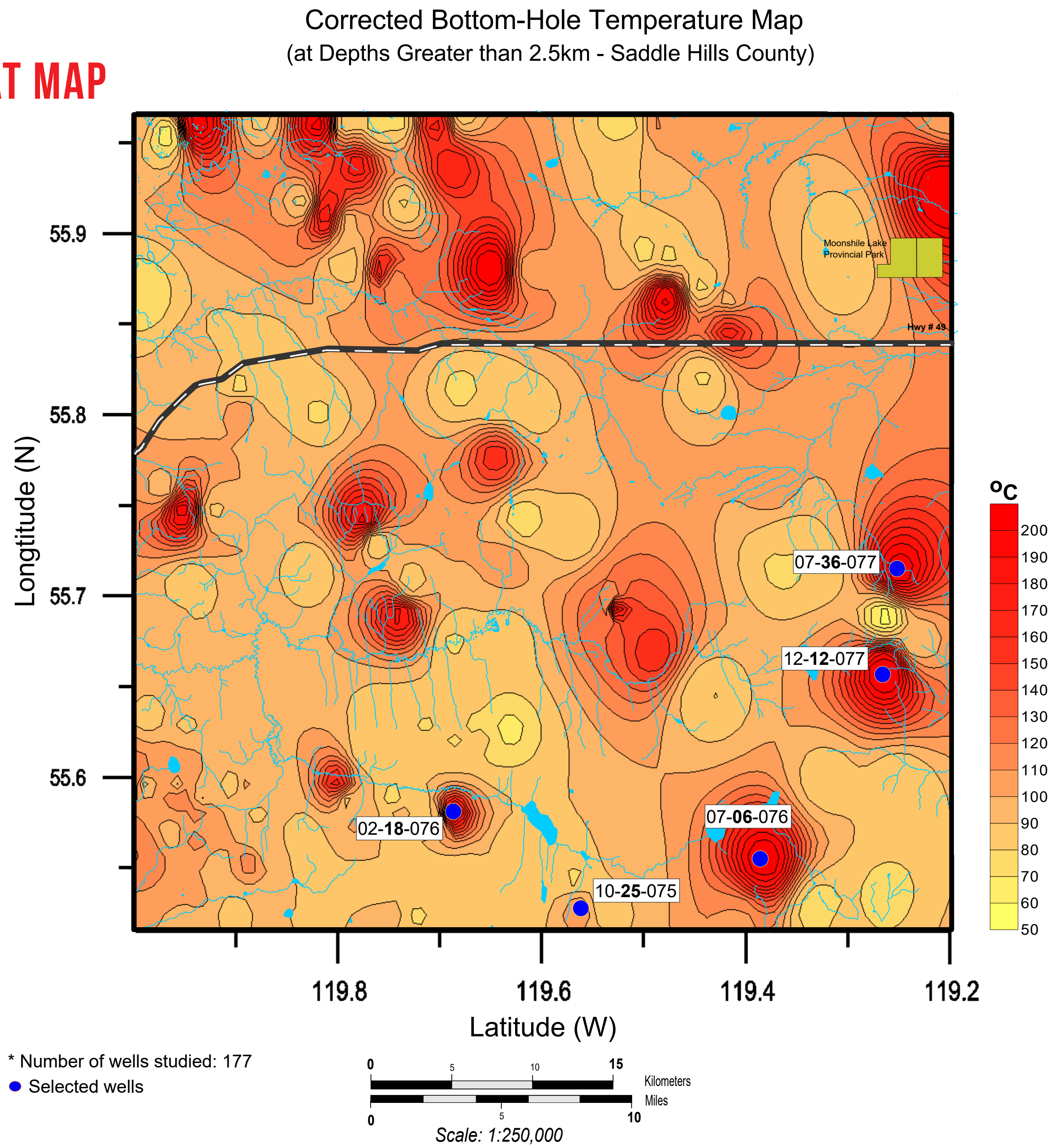
The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

RESEARCH RESULTS: SADDLE HILLS COUNTY

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

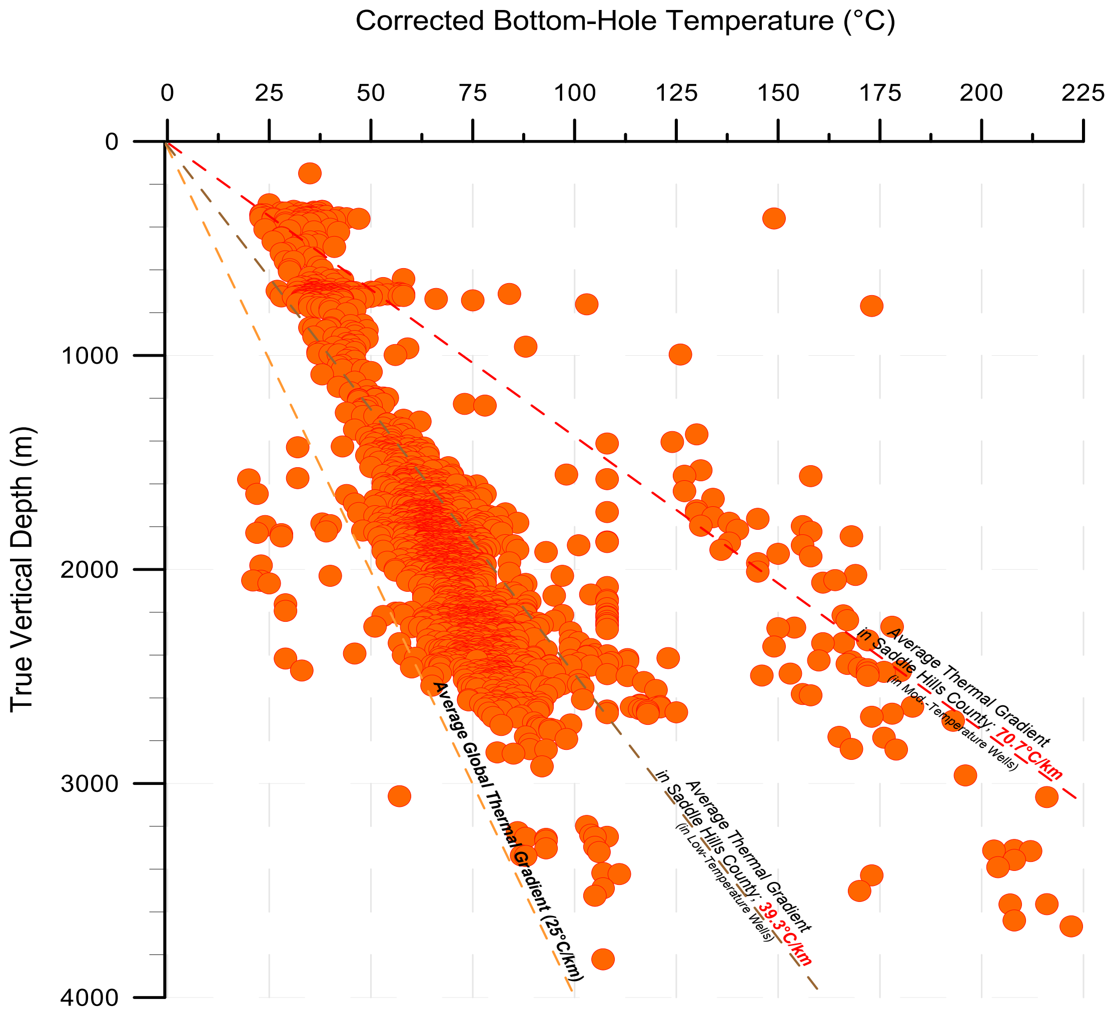
HEAT MAP



RESEARCH RESULTS: SADDLE HILLS COUNTY

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 5 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Granite Wash F. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/12-12-077-09W6/00	3562.5	30.1	216	225	Kelt Expl Ltd
100/07-36-077-09W6/00	3563.5	-53.5	207	210	Phillips Petrl Cda Ltd
100/07-06-076-09W6/00	3638.7	-32.9	208	210	BP Cda Enrg Grp ULC
100/02-18-076-11W6/00	3666.1	-73.2	222	225	Imperial Oil Rsrcs Ltd(2)
100/10-25-075-11W6/00	3820.2	-53.5	107	125	Insignia Enrg Ltd

KEY TAKEAWAYS

- The identified productive geothermal formation in your area is the **Granite Wash** formation
- There are two temperature data sets in the study area: a low-moderate set with an indicated gradient of **39.3ºC/km** and a moderate-high set with an indicated temperature gradient of **70.7ºC/km.** These are both significantly higher than the global average.
- There is potential for **direct use and power generation** activities in the study area

RECOMMENDATION & NOTES

Our investigation of Saddle Hills County has uncovered a number of beneficial and potentially detrimental factors for geothermal development. There are consistently superior temperature readings that increase with well depth. However, though the Devonian strata has a moderate thickness (300m), the only identified geothermal formation in the study area is quite thin (25m). Therefore, the productive formation may be hot enough to support sustained geothermal production but may not contain sufficient fluid. It is recommended that the studies encompassing the entire County be undertaken which: validate the high temperature well data, find areas with thicker sedimentary cover, and examine water production from hydrocarbon extraction activities to provide an indication as to the water content of the potential geothermal formation.

September 25, 2018

Geothermal Analysis

Saddle Lake #125

Study by Terrapin Geothermics

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

↓

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

↓

Project Decision

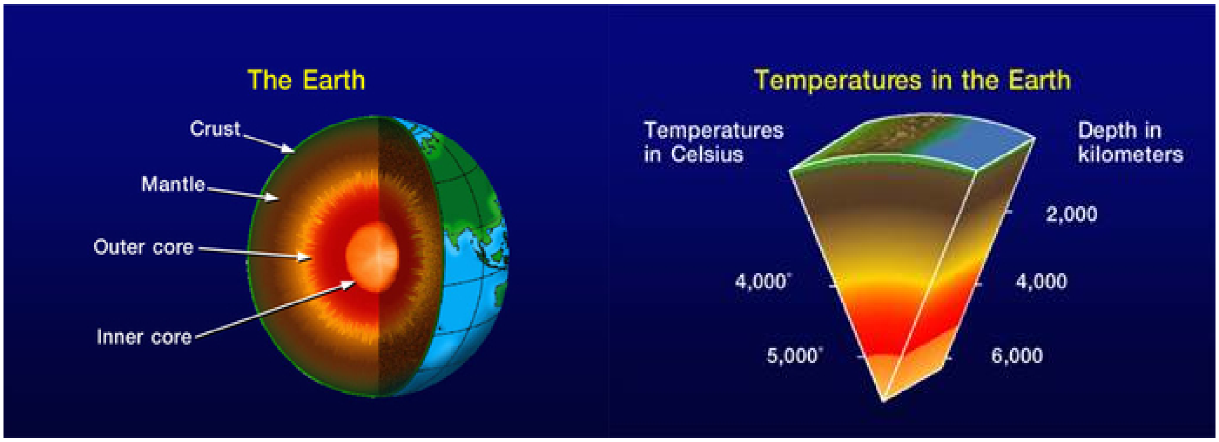
Geo-exchange	Direct Use	Power Generation

↓

Project Development

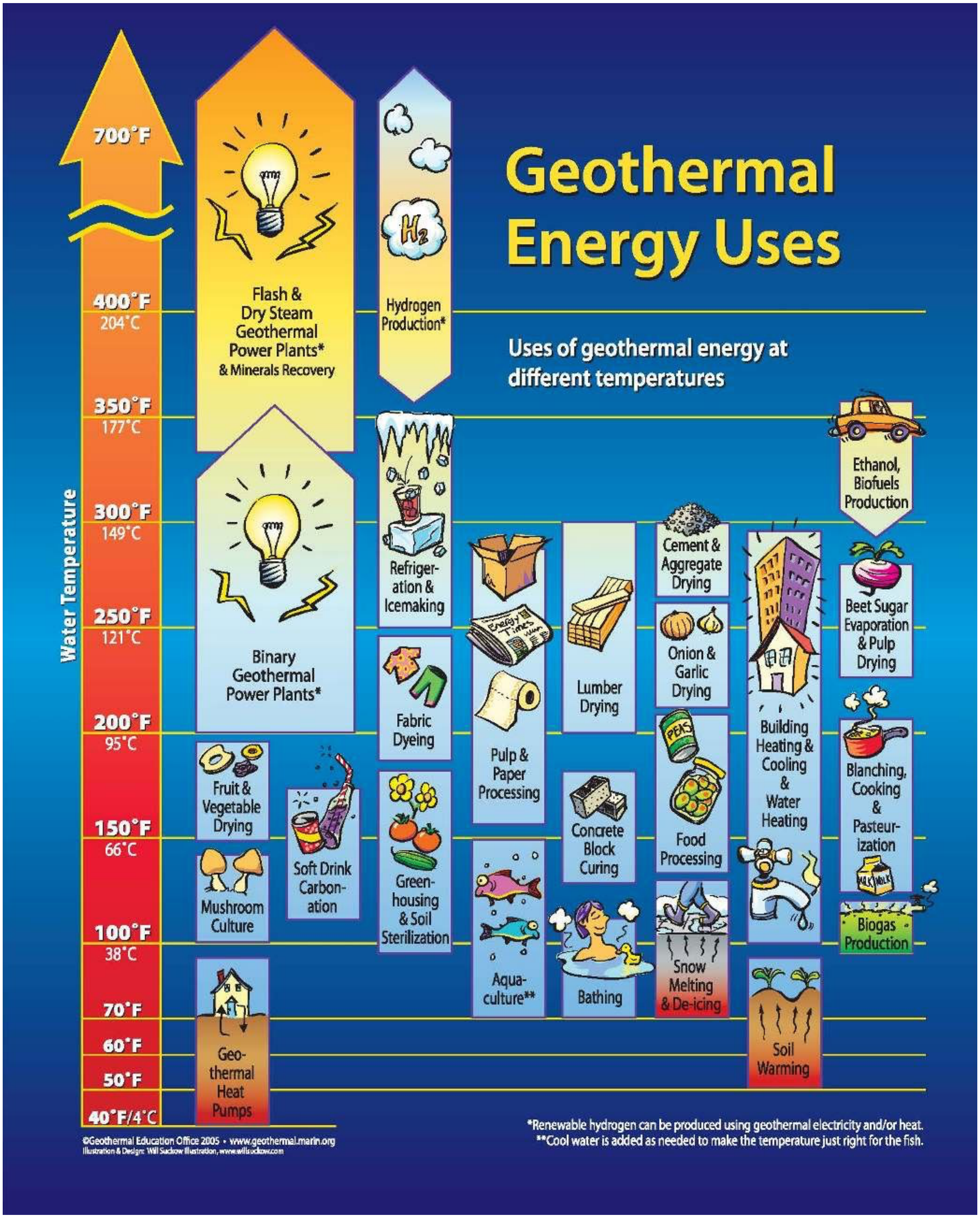
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180°C and above), medium (100-180°C), and low (80-100°C) temperature resources with fluids under 80°C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235°C or above); flash plants (turning geothermal fluids of at least 150°C into steam to drive a turbine); and binary power plants (using hot waters above 80°C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180°C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

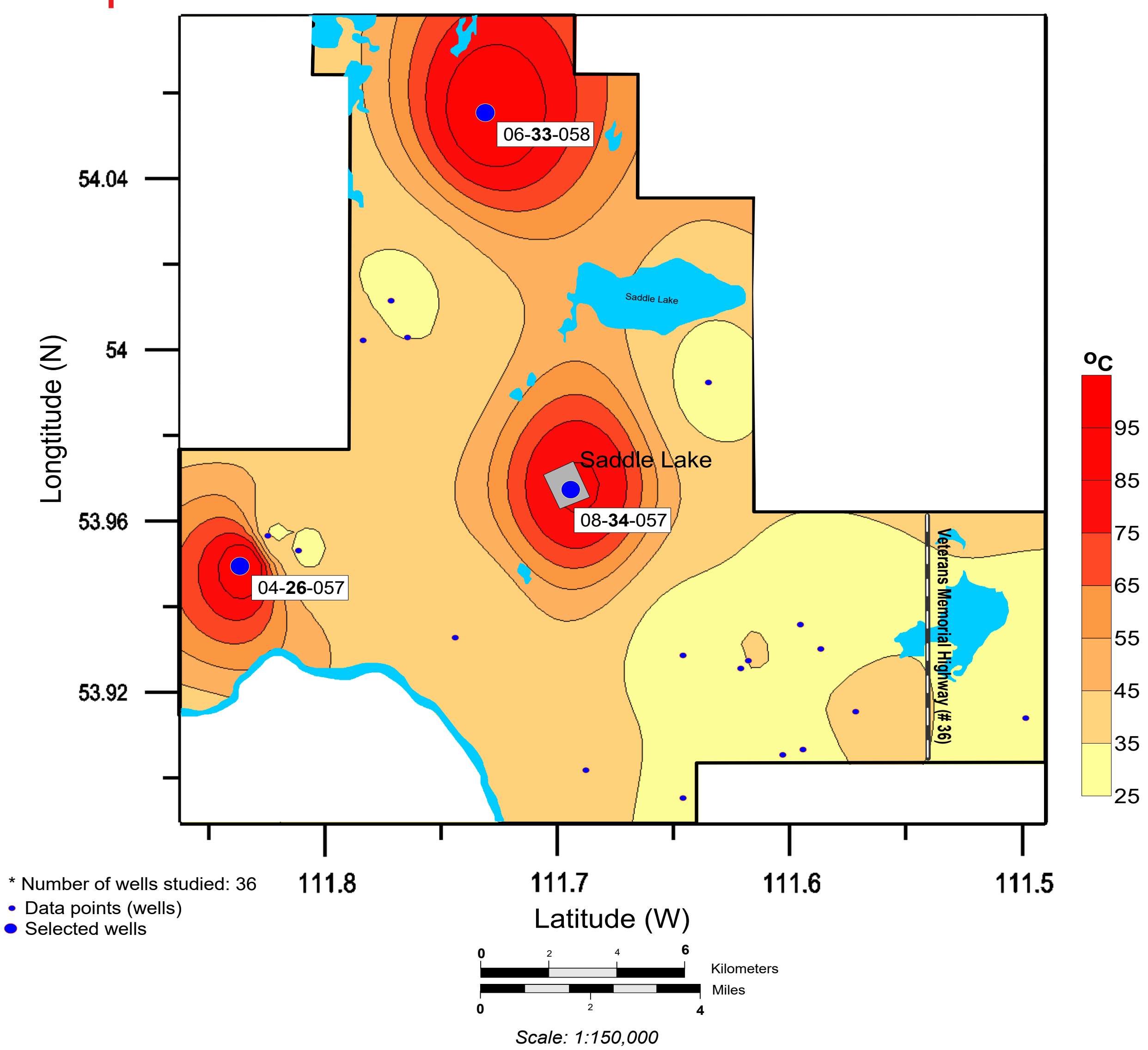
Research Results: Saddle Lake #125

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

Heat Map

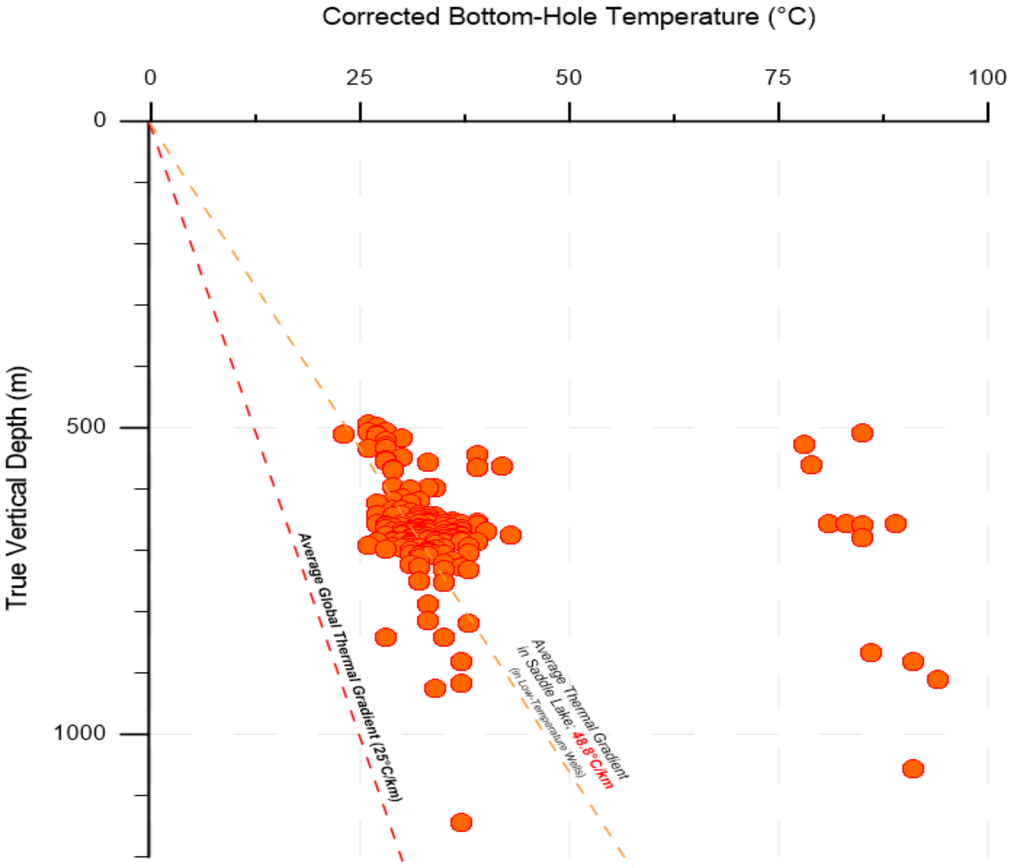
Corrected Bottom-Hole Temperature Map
(at Depths Greater than 0.7km - Saddle Lake #125)



Research Results: Saddle Lake #125

Temperature Gradient

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



Top 3 Representative Wells

Well ID	Current Depth (mVD)	Depth to Hot Formation- Watt Mnt. F. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/04-26-057-13W4/00	911	-100.5	94	120	TAQA North Ltd
100/06-33-058-12W4/00	880.6	-130.9	91	120	Imperial Oil Ltd
100/08-34-057-12W4/00	867.5	-144	86	110	Imperial Oil Ltd

Key Takeaways

- None of the wells in the study area reached a potential geothermal formation. It is assumed that the **Watt Mountain** formation would occur at a depth between **930m and 1110m**.
- The average thermal gradient in the study area is **48.8°C/km.** That is **95% better** than the global average.
- There is one well drilled in the centre of the townsite which has a bottom-hole temperature of 86°C. This indicates that there is strong potential for **direct use** applications at the townsite.

Recommendation & Notes

The temperatures recorded in assets located within the boundaries of Saddle Lake #125 indicate that there may be sufficient temperatures to support direct-use applications. However, none of these assets are drilled to an appropriate depth to determine the specific geology, and therefore the geothermal potential, of the study area. It is recommended that further investigation be undertaken to identify geological structures underlying the study area deeper than 900m as they relate to geothermal potential. Upon confirming beneficial temperature and geological data, Terrapin recommends the undertaking of mapping activities to understand the fluid flows within target formations, and the creation of detailed thermal energy potential models to provide a basis for understanding the heat-use opportunities in the area. This knowledge can provide direction for future development activities.

September 25, 2018

Geothermal Analysis

Smoky Lake County

Study by Terrapin Geothermics

terrapin

For further information,
contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).

Devonian A geological period/age lasting from 419.2 to 358.9 million years ago.

Formation An individual geological unit with a well-defined age, stratigraphic horizon and rock type.

Frostline The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above 0^{o}C.

Permeability The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.

Porosity A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.

Reservoir A regional scale, resource-rich formation.

Sedimentary Layers Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.

Stratum (plural: strata) A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

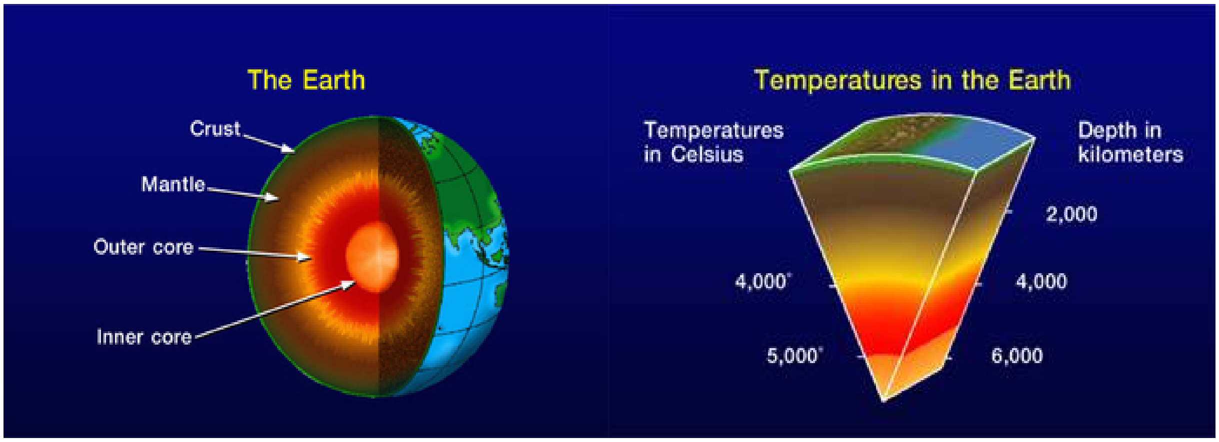
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

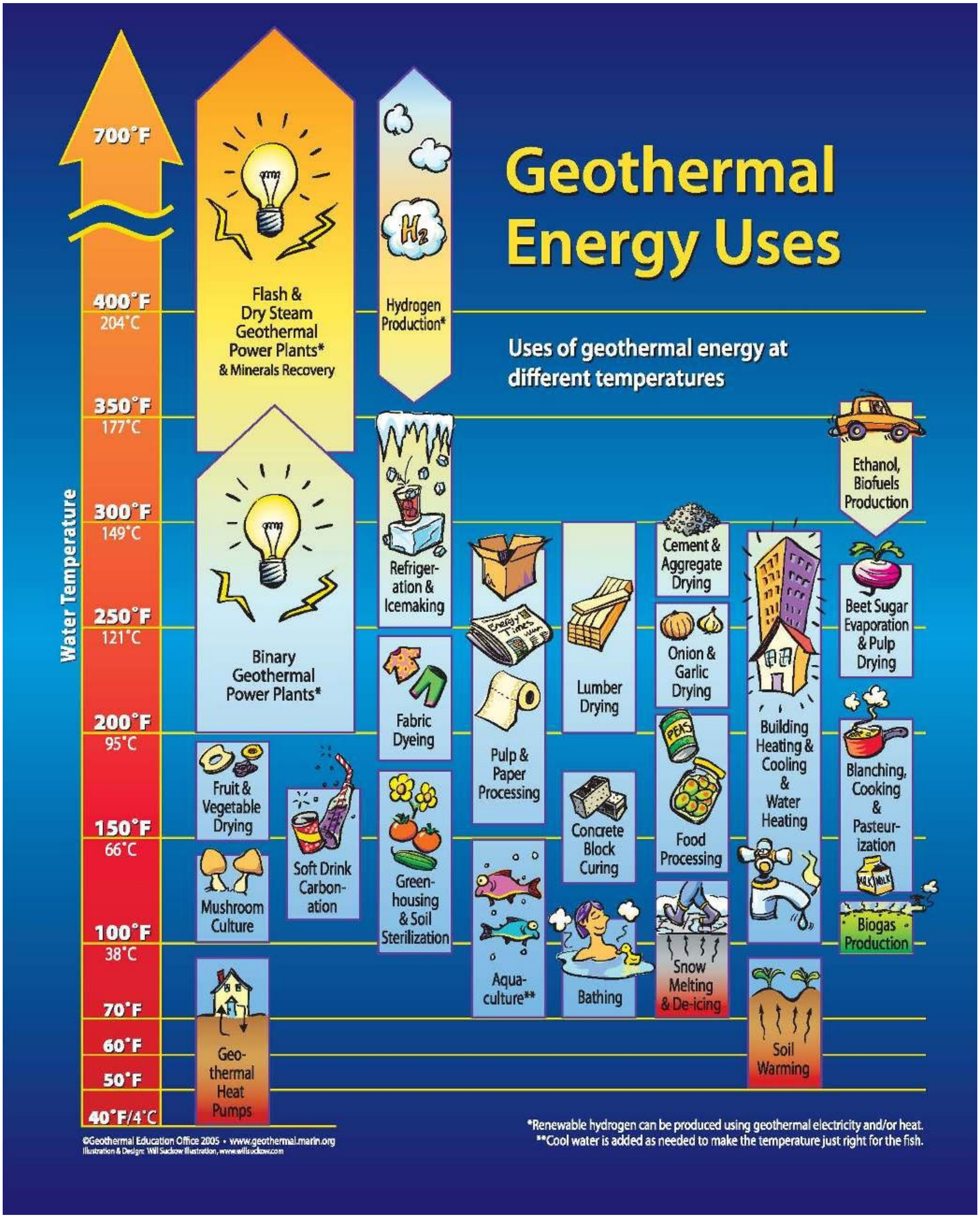
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180^{o}C and above), medium (100-180^{o}C), and low (80-100^{o}C) temperature resources with fluids under 80^{o}C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235^{o}C or above); flash plants (turning geothermal fluids of at least 150^{o}C into steam to drive a turbine); and binary power plants (using hot waters above 80^{o}C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180^{o}C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

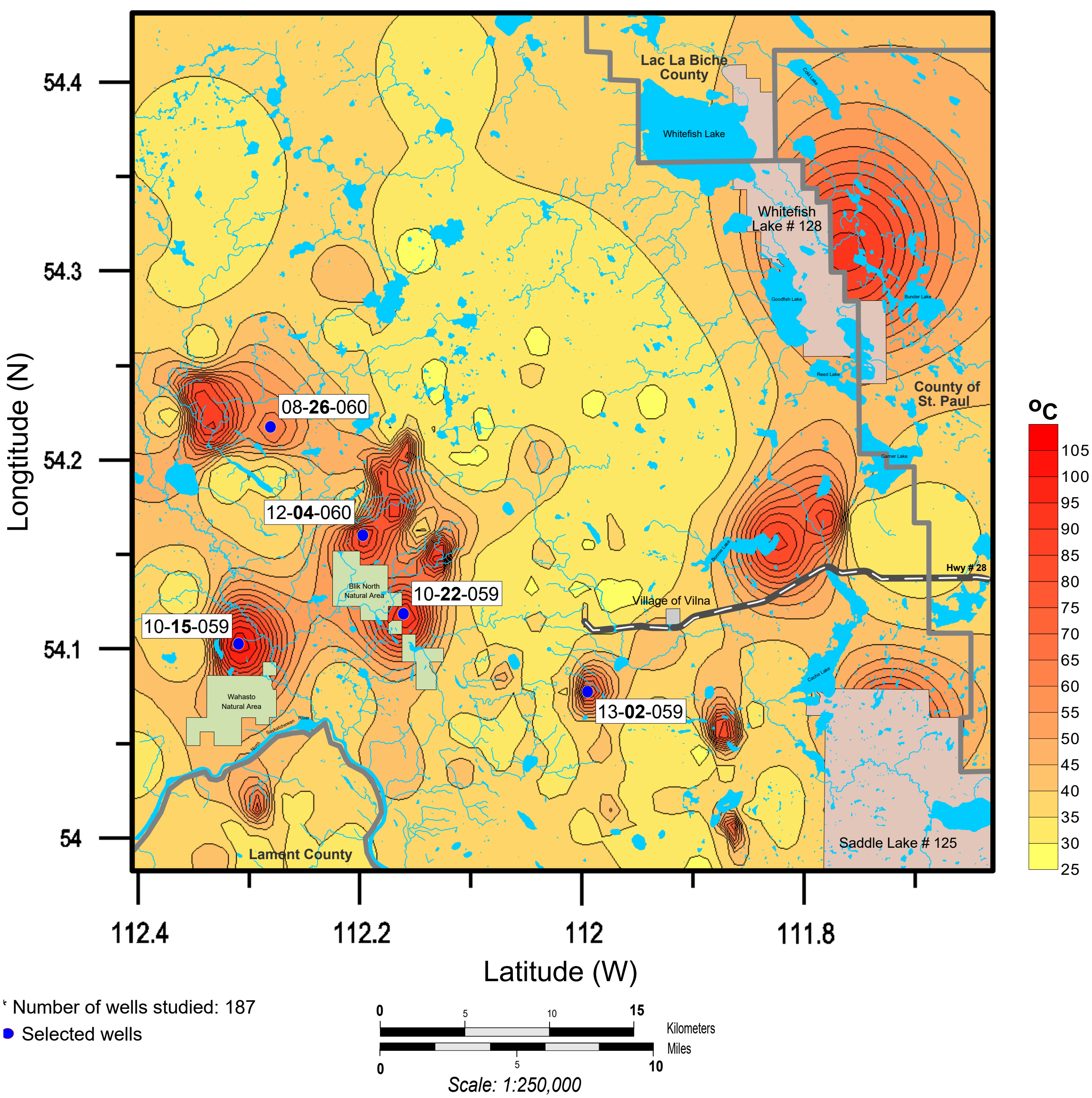
RESEARCH RESULTS: SMOKY LAKE COUNTY

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

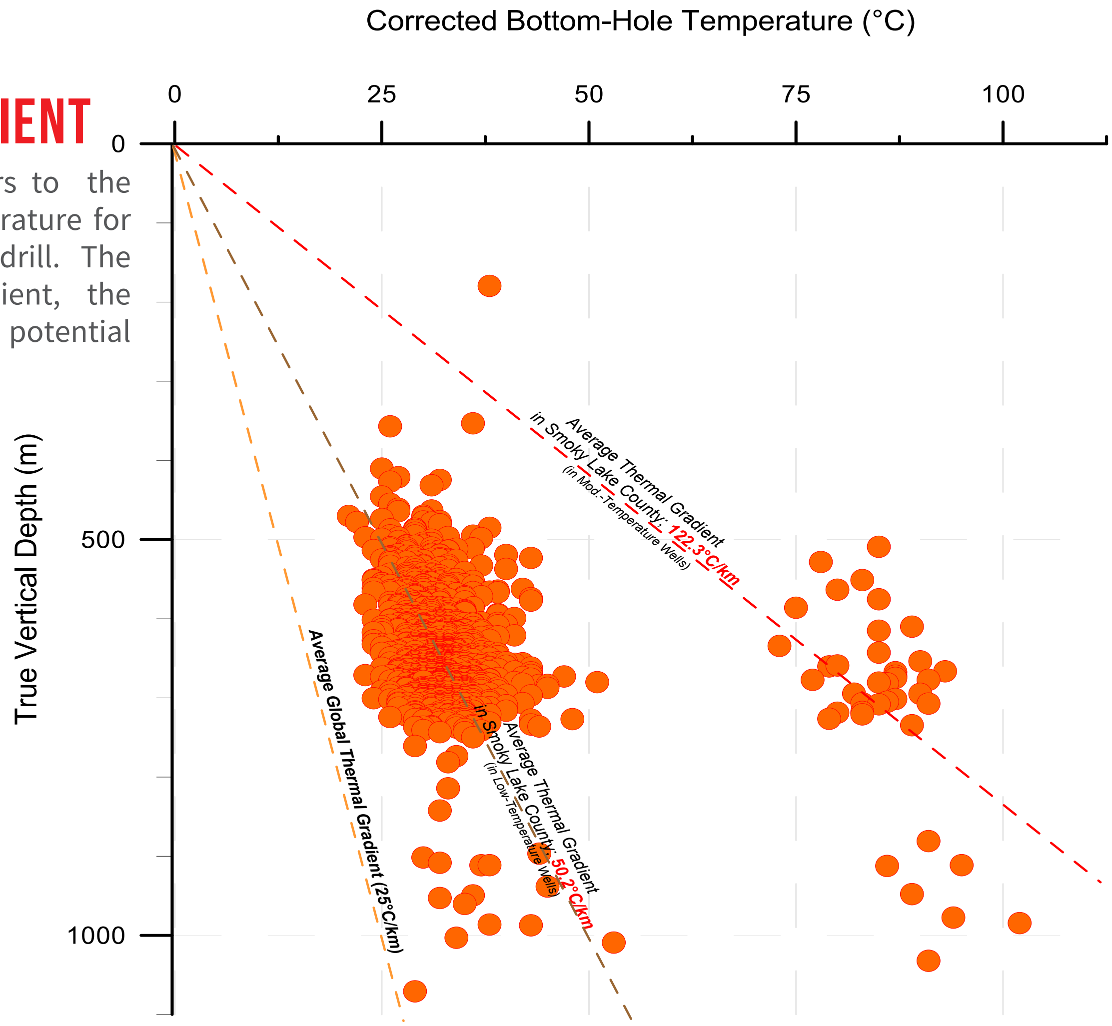
Corrected Bottom-Hole Temperature Map
(at Depths Greater than 0.7km - Smoky Lake County)

HEAT MAP



terrapin

RESEARCH RESULTS: SMOKY LAKE COUNTY



TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.

TOP 5 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Devonian Strata (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/10-15-059-16W4/00	984.2	-404.4	102	180	Cdn Nat Rsrcs Ltd
100/13-02-059-14W4/00	710	-7.4	78	120	Brenda Mines Ltd
100/10-22-059-15W4/00	977.2	-349.3	94	180	TAQA North Ltd
100/12-04-060-15W4/00	947.6	-295.7	89	180	Frontier O&G Ltd
100/08-26-060-16W4/00	1901.4	-1256.4	62	80	Town of Smoky Lake

KEY TAKEAWAYS

- There are **no previously identified productive geothermal formations** in the study area
- There are two clusters of temperature readings in your area, indicating gradients of **50.2ºC/km** and **122.3ºC/km.** These are likely influenced by the shallowness of wells in the subject area.
- Based on currently available data, there is potential for **geo-exchange** activities in your region.

RECOMMENDATION & NOTES

Our study of Smoky Lake County has uncovered factors that may be detrimental to large-scale geothermal development. First, though the Devonian-aged strata are quite thick (1350m), there are no previously identified productive geothermal formations present in the geological record. As well, the majority of wells in the study area are drilled to depths less than 750m meaning that temperature readings are likely to have been influenced by the thermal conductivity of shallow rock layers, potential anomalous temperature readings, improper measurement techniques, or data entry errors and has led to an overestimation of the temperature potential in the region. It is recommended that the County investigate the geothermal potential of localized Devonian-aged formations and gather temperature measurements from deeper than 1000m to fully understand the geothermal potential of the area.

September 25, 2018

Geothermal Analysis

Athabasca

Study by Terrapin Geothermics

terrapin

For further information,
contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

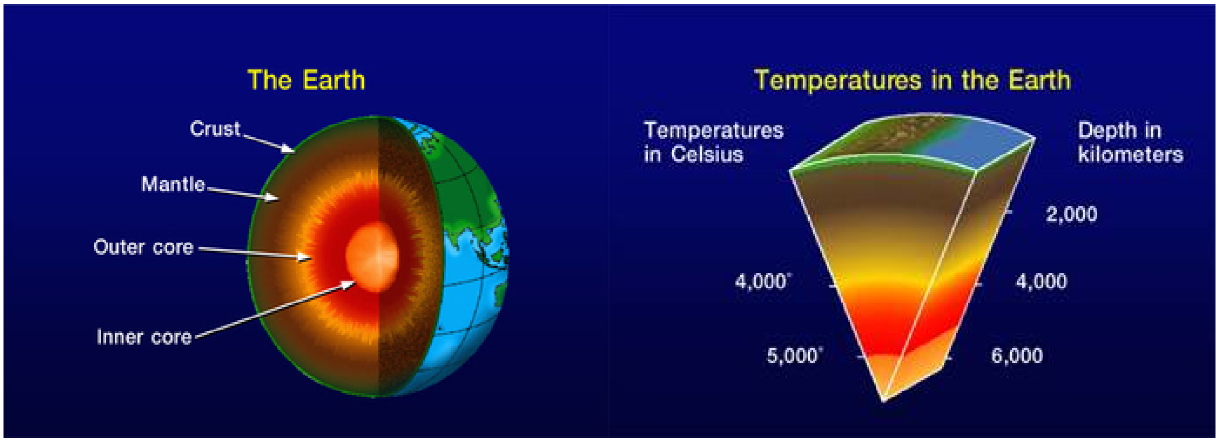
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

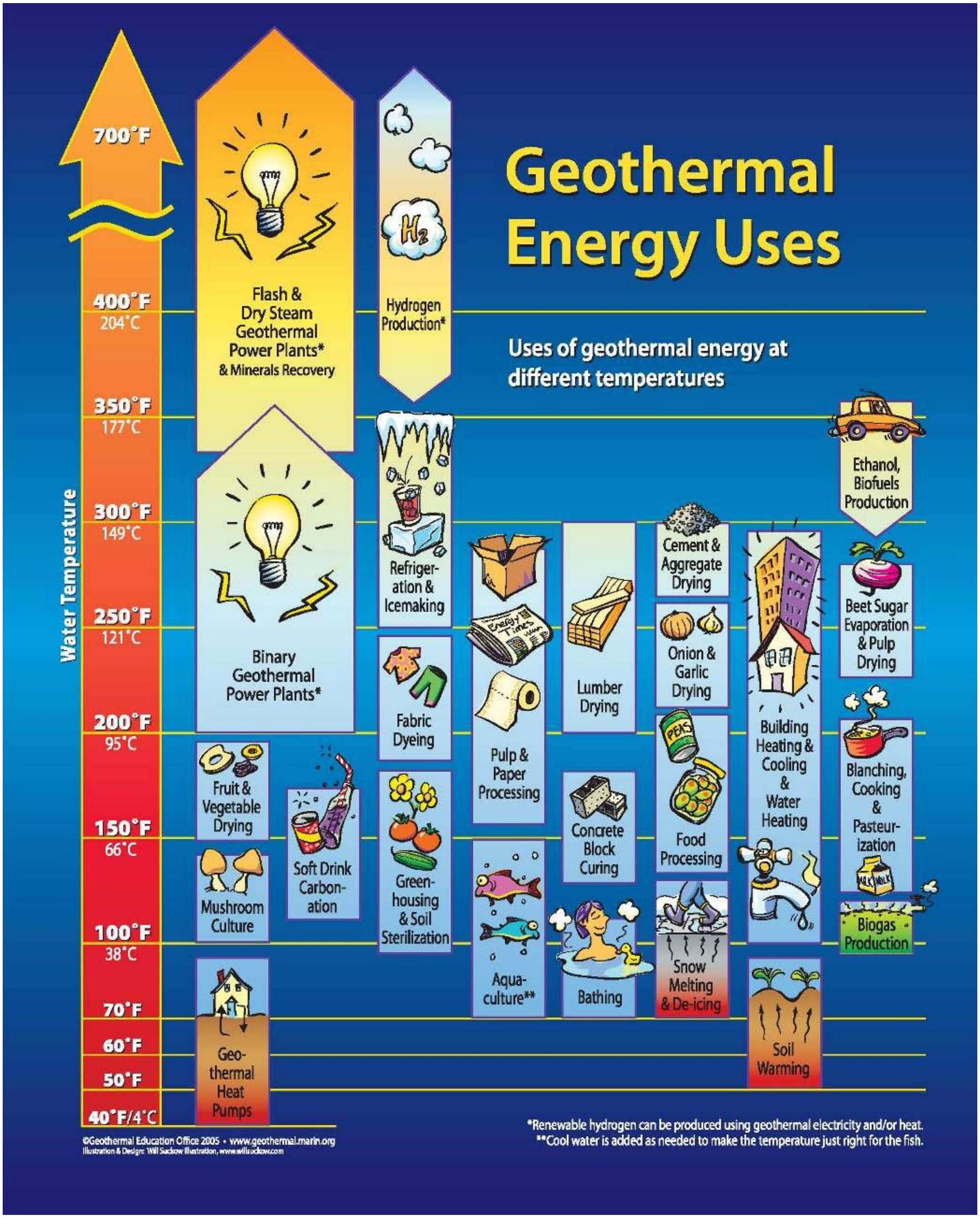
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180°C and above), medium (100-180°C), and low (80-100°C) temperature resources with fluids under 80°C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235°C or above); flash plants (turning geothermal fluids of at least 150°C into steam to drive a turbine); and binary power plants (using hot waters above 80°C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180°C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

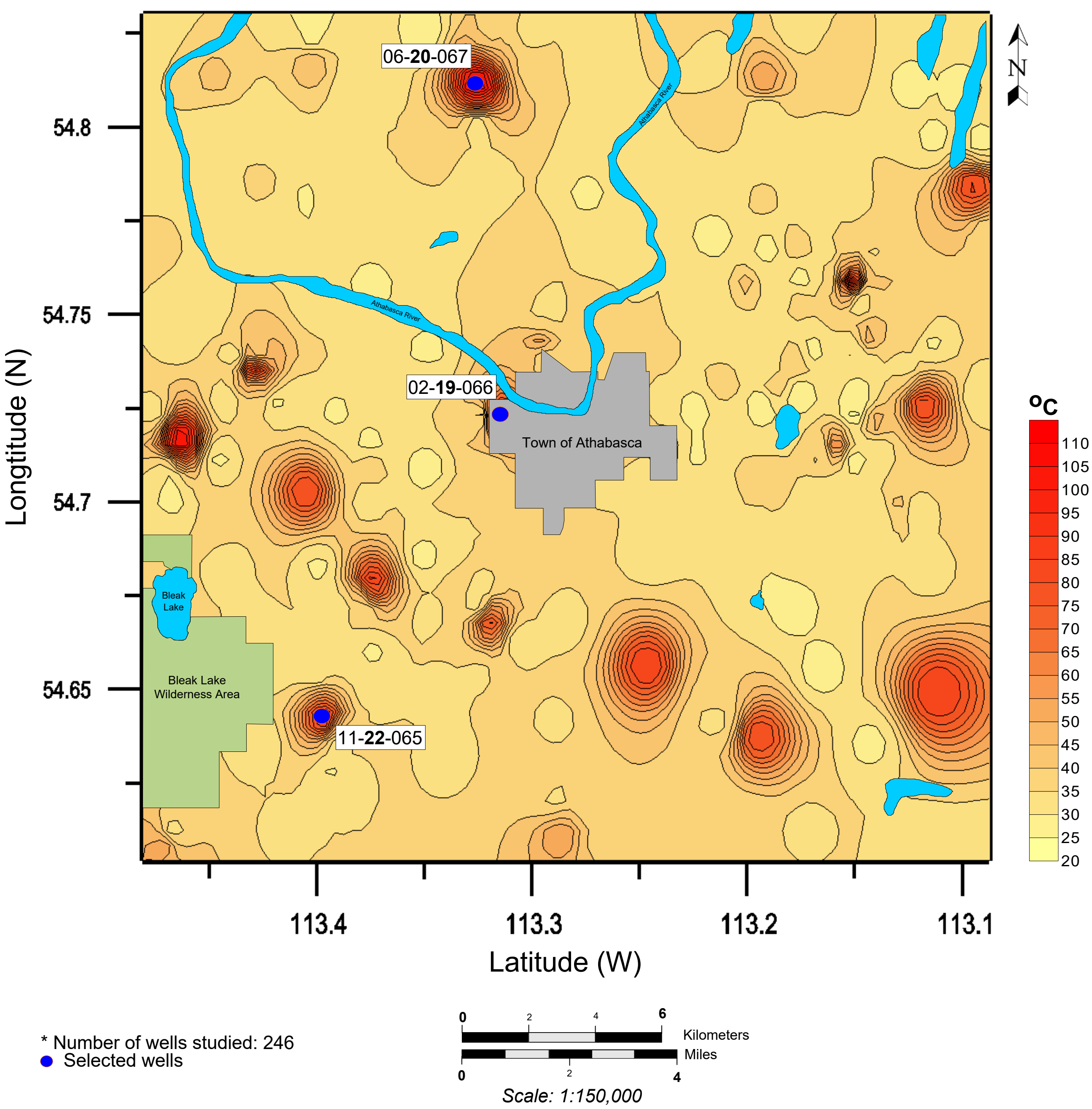
RESEARCH RESULTS: ATHABASCA

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

Corrected Bottom-Hole Temperature Map
(at Depths Greater than 0.6 km - Town of Athabasca)

HEAT MAP

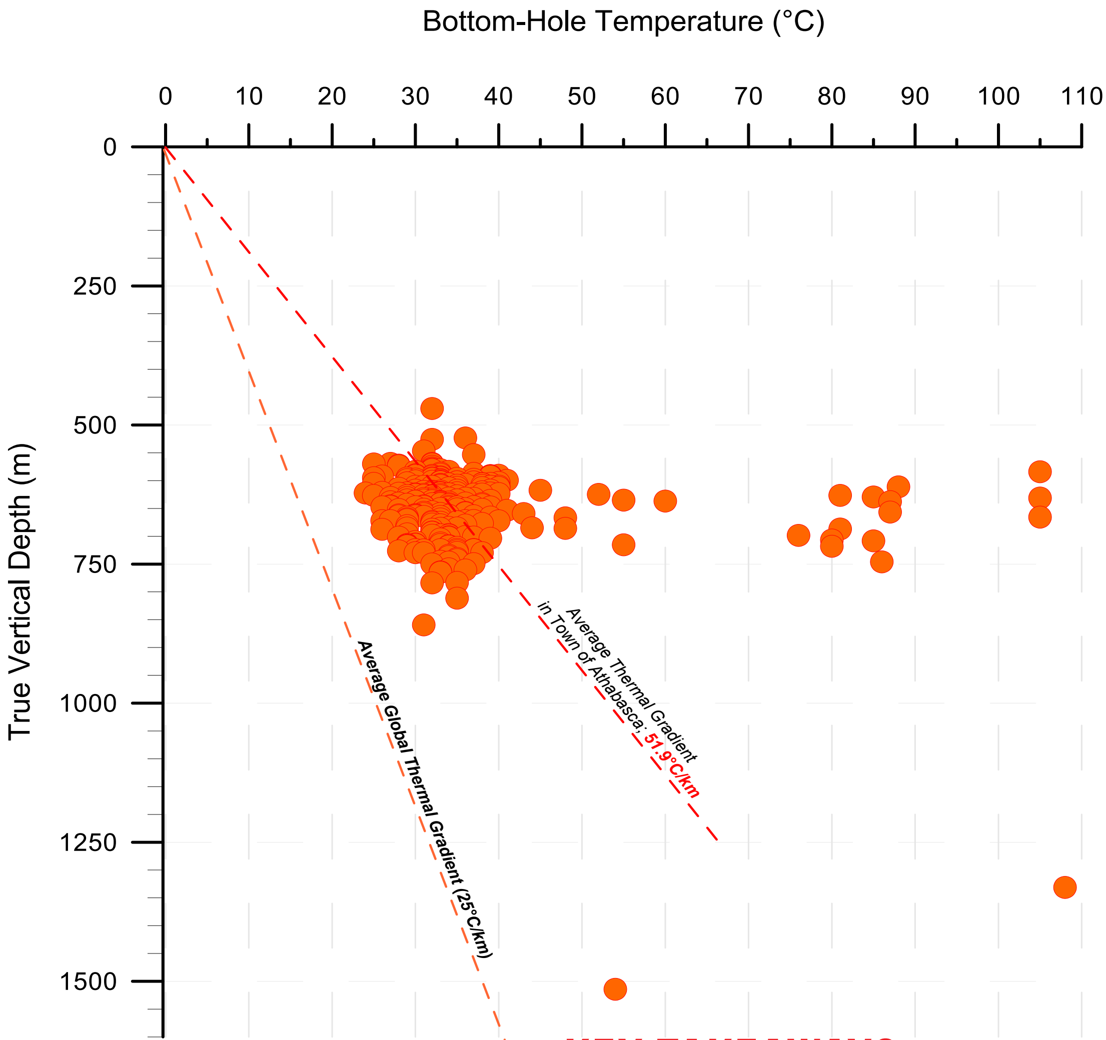


* Number of wells studied: 246
Selected wells

RESEARCH RESULTS: ATHABASCA

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 3 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation- Devonian Strata (m)	Corrected Bottom-Hole Temperature (°C)	Expected Temperature at the Base of Target Formations (°C)	Current Operator
100/06-20-067-22W4/00	1335	-749.8	108	120	Husky Oil Oprtns Ltd
100/02-19-066-22W4/00	613.6	-18.6	88	100	Cavalier Enrg Ltd
100/11-22-065-23W4/00	748.6	-70.7	86	100	Cdn Nat Rsrcs Ltd

KEY TAKEAWAYS

- The identified geothermally productive formation underlying the study area is the **Leduc** formation.
- The indicated temperature gradient is **51.9°C/km**, likely influenced by the shallowness of the wells in the area. The majority of wells are drilled to less than **750m**.
- There is potential for **geo-exchange** activities and possible **direct use** in the surrounding area, particularly the western limits of the town.

RECOMMENDATION & NOTES

Our study of the town of Athabasca has uncovered a number of factors that may be detrimental to large-scale geothermal development. First, though the Devonian strata is quite thick in the region, the water bearing formation is relatively thin and may not contain enough fluid to support sustained direct-use activities. Second, the majority of wells in the study area are shallow. This means that the temperature readings are likely to have been influenced by the thermal conductivity of shallow rock layers, potentially anomalous high temperature readings, improper measurement techniques, or data entry errors. This may have led to an overestimation of the temperature potential in the region. Investigation into deeper geological structures in the study area and validation of the temperature data of the anomalous wells is suggested in order to evaluate potential direct-use opportunities.

September 25, 2018

Geothermal Analysis

Beaverlodge

Study by Terrapin Geothermics

For further information,
contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

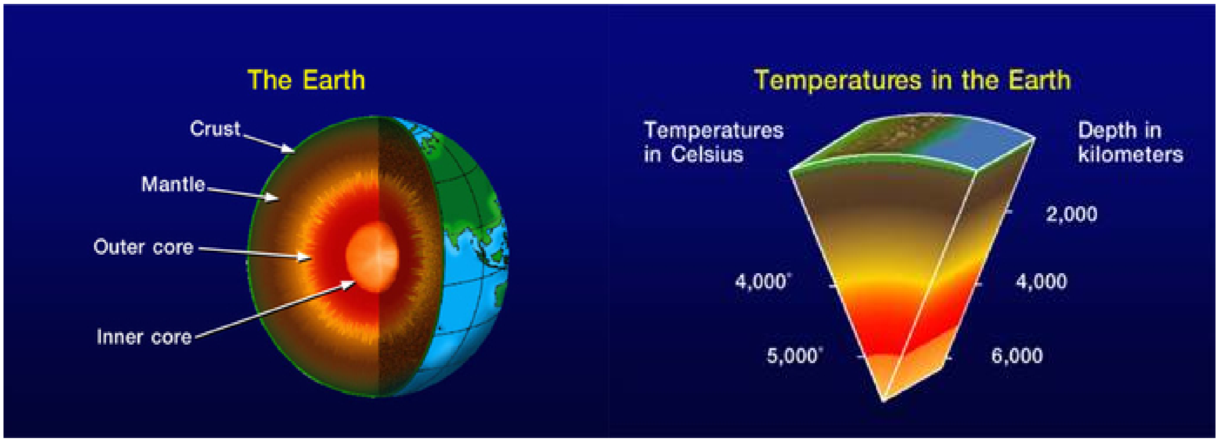
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

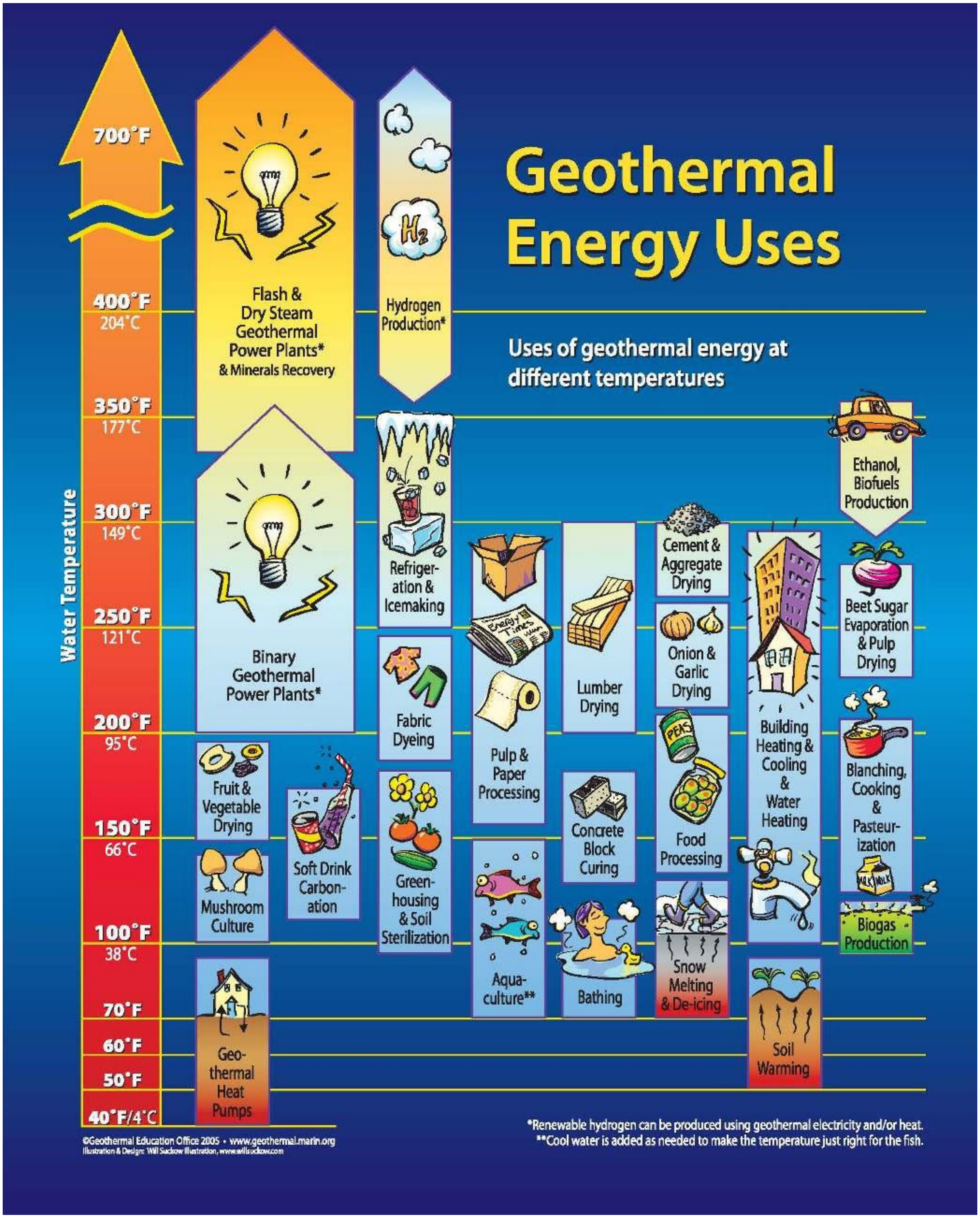
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180°C and above), medium (100-180°C), and low (80-100°C) temperature resources with fluids under 80°C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235°C or above); flash plants (turning geothermal fluids of at least 150°C into steam to drive a turbine); and binary power plants (using hot waters above 80°C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180°C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

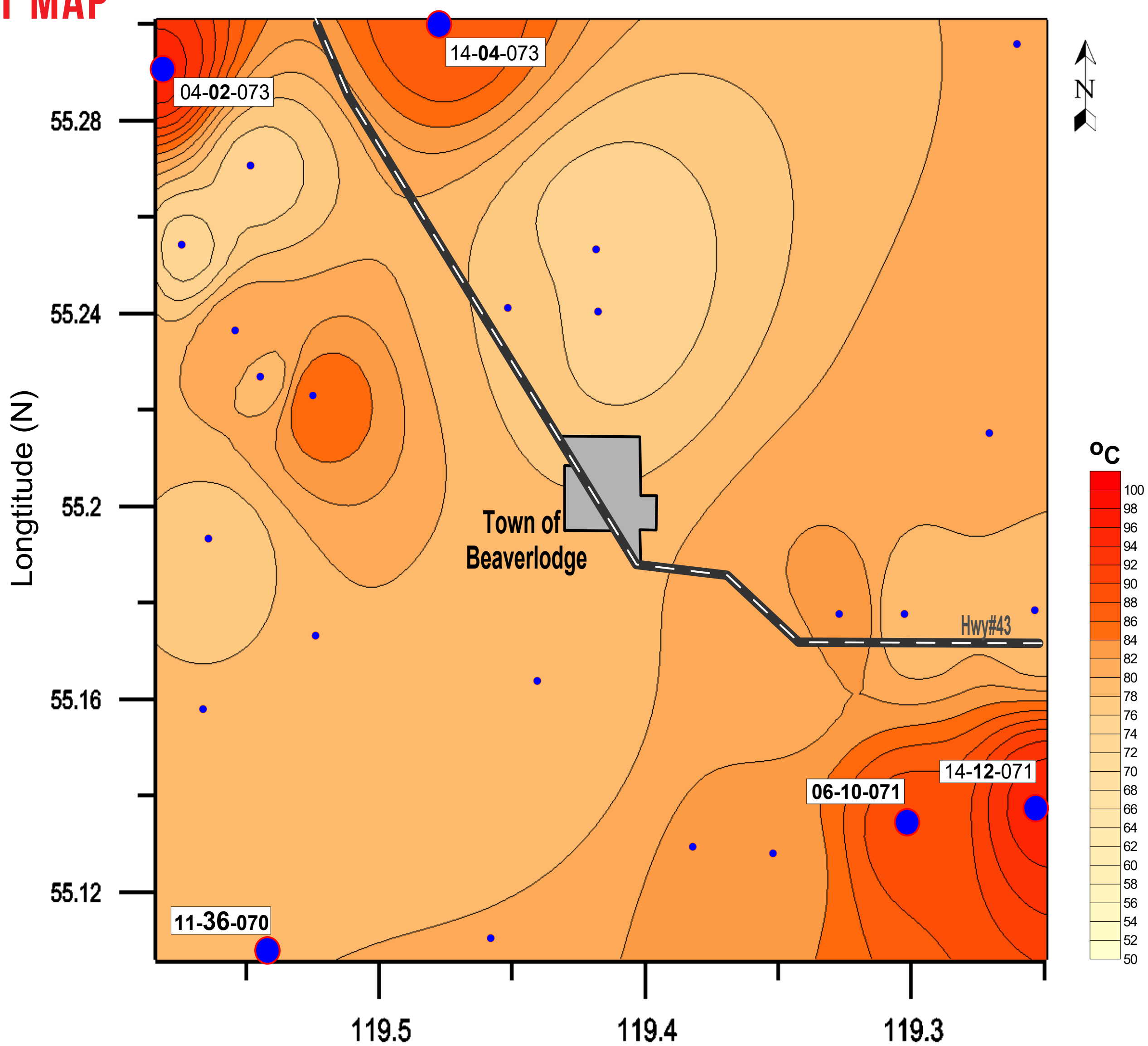
RESEARCH RESULTS: BEAVERLODGE

CONTEXT

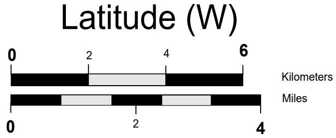
Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

HEAT MAP

Corrected Bottom-Hole Temperature Map
(at Depths Greater than 2.5km - Town of Beaverlodge)



* Number of wells studied: 26
- Data Points (wells)
- Selected wells

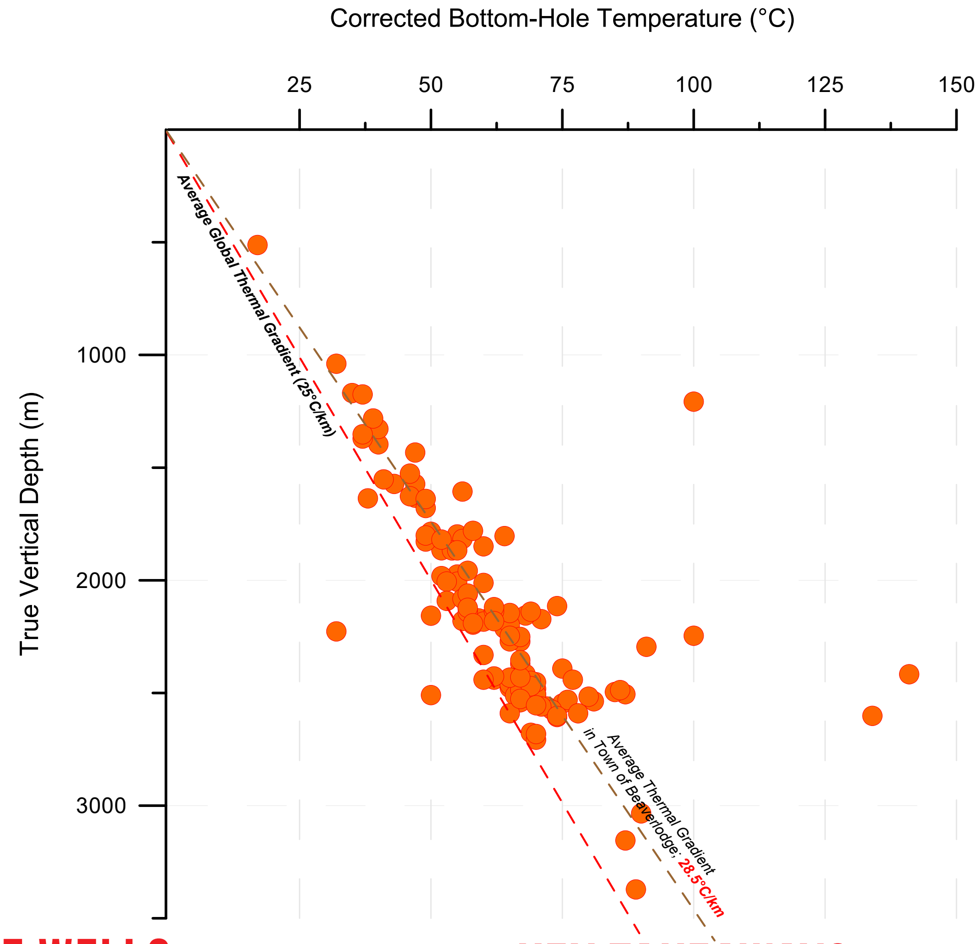


Scale: 1:150,000

RESEARCH RESULTS: BEAVERLODGE

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 5 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Leduc (m)	Corrected Bottom-Hole Temperature (°C)	Expected Temperature at Leduc F. (°C)	Current Operator
100/04-02-073-11W6/00	3153.5	917.7	95	124	Northwstrn Util Ltd
100/11-36-070-11W6/00	3033.3	1037.9	98	111	Cenovus Enrg Inc
100/06-10-071-09W6/00	2535.9	1535.3	89	110	Cenovus Enrg Inc
100/14-04-073-10W6/00	2515.3	1555.9	88	107	Repsol O&G Cda Inc
100/14-12-071-09W6/00	2504.5	1566.7	95	106	Hoc Enrg Corp

KEY TAKEAWAYS

- The ideal formation for geothermal production in your area is the **Leduc** formation.
- The geothermal gradient surrounding Beaverlodge is **28.5°C/km**. This aligns closely with the global average.
- There is strong potential for **direct-use applications** in areas to both the northwest and southeast of Beaverlodge.

RECOMMENDATION & NOTES

Our study of Beaverlodge has uncovered a number of factors which indicate that the development of direct-use geothermal may be feasible. There are a number of wells drilled deeper than 3000m with consistently favourable temperature readings. Measurements from these wells also show that the potential fluid-bearing formations underlying Beaverlodge are thick enough (205.7m) to support geothermal production. Terrapin strongly recommends that Beaverlodge undertake targeted research that includes temperature validation activities, mapping the fluid flows within target formations, and creating detailed thermal energy potential models to provide a basis for understanding the heat-use opportunities in the area. This knowledge can provide direction for future land use planning and development activities.

September 25, 2018

Geothermal Analysis

Bonnyville

Study by Terrapin Geothermics

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above 0^{o}C.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

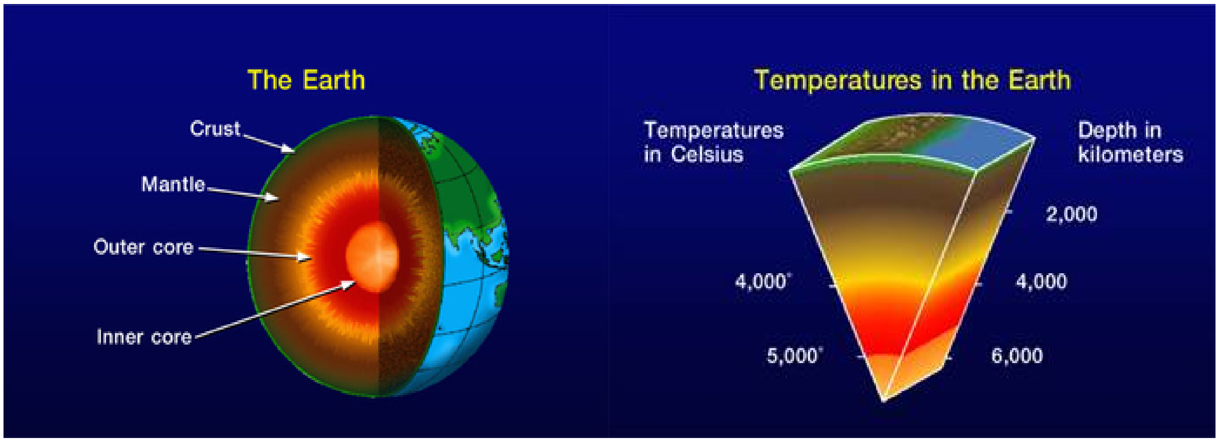
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

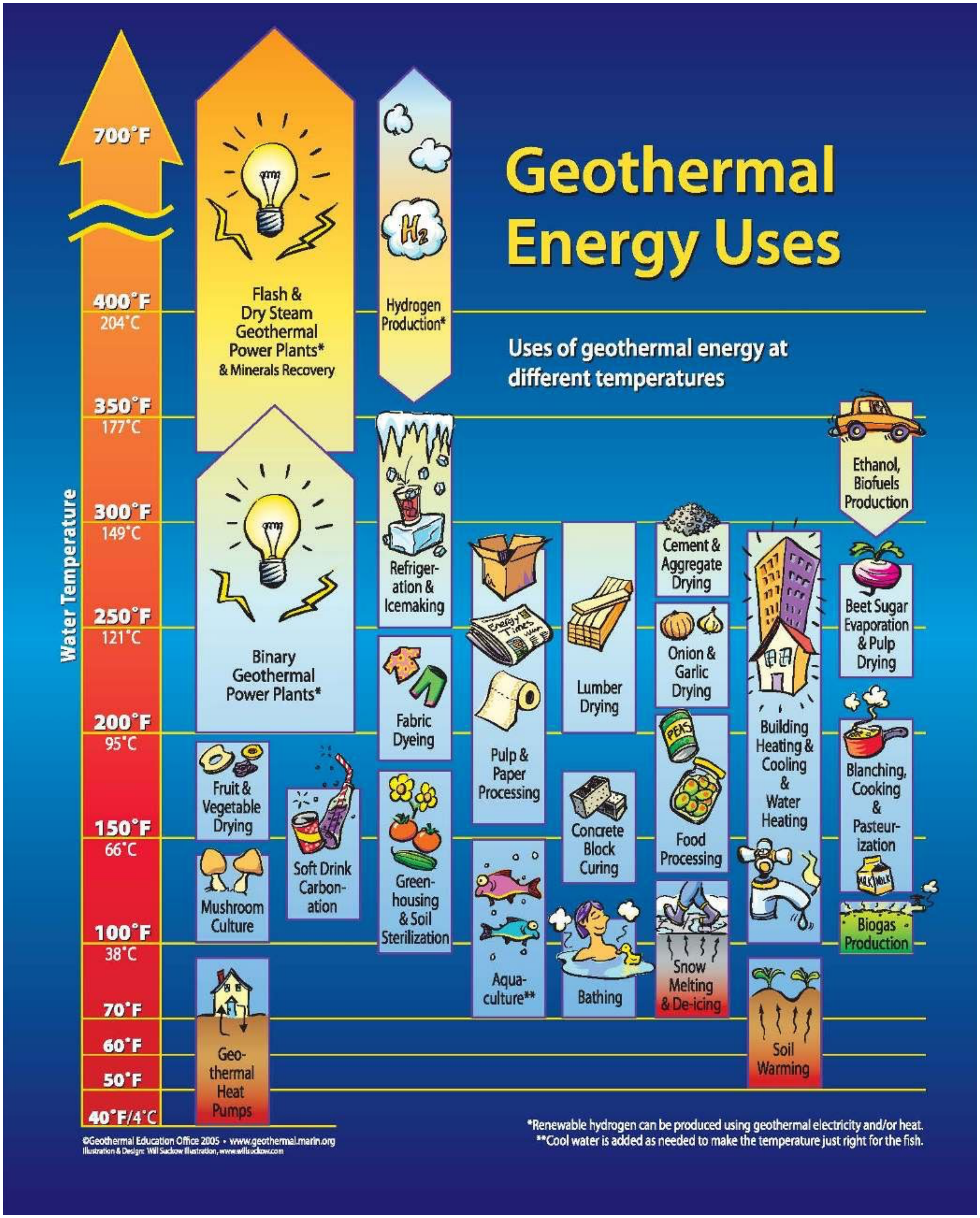
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160ºC and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180°C and above), medium (100-180°C), and low (80-100°C) temperature resources with fluids under 80°C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235°C or above); flash plants (turning geothermal fluids of at least 150°C into steam to drive a turbine); and binary power plants (using hot waters above 80°C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180°C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

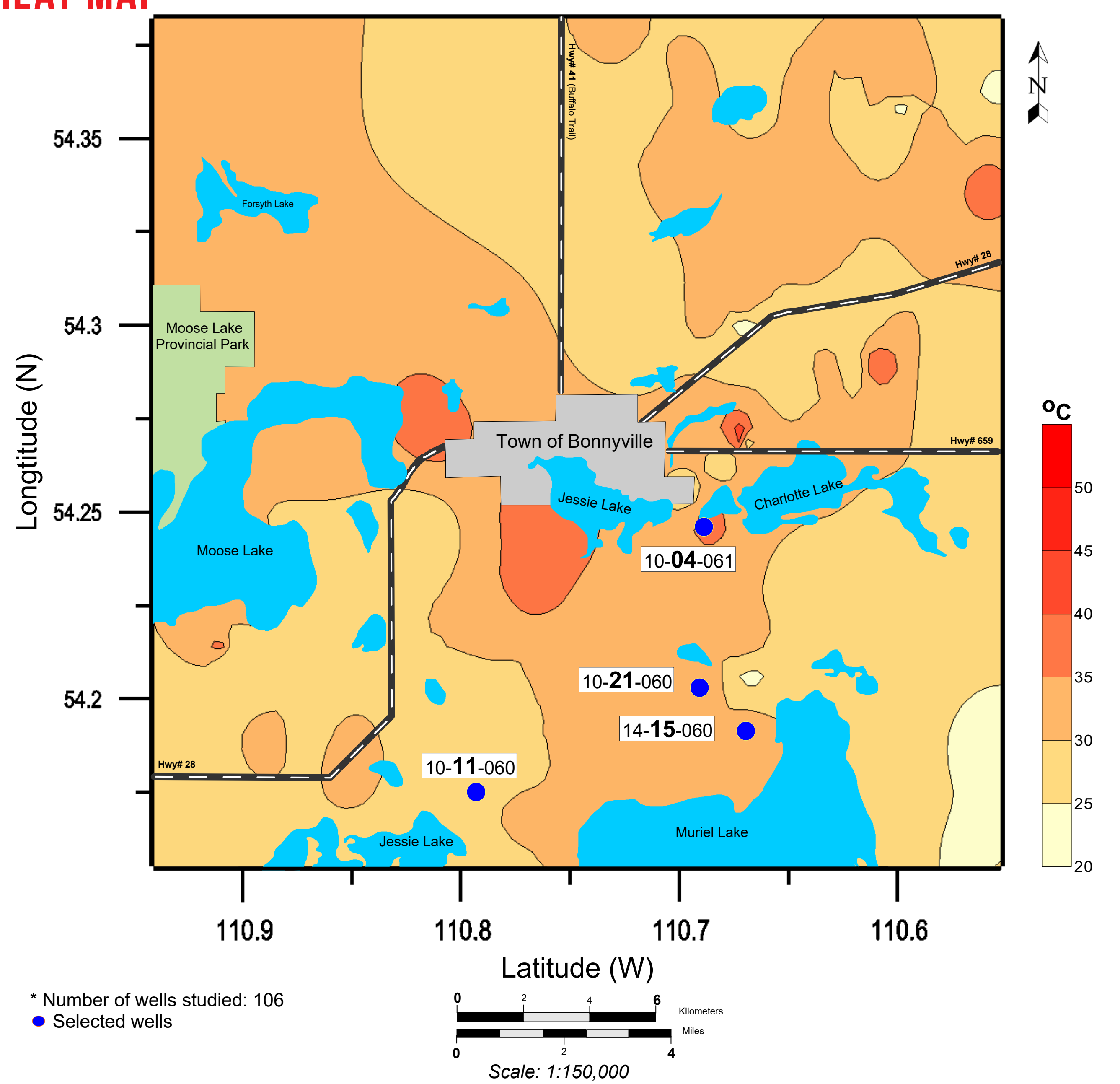
RESEARCH RESULTS: BONNYVILLE

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

HEAT MAP

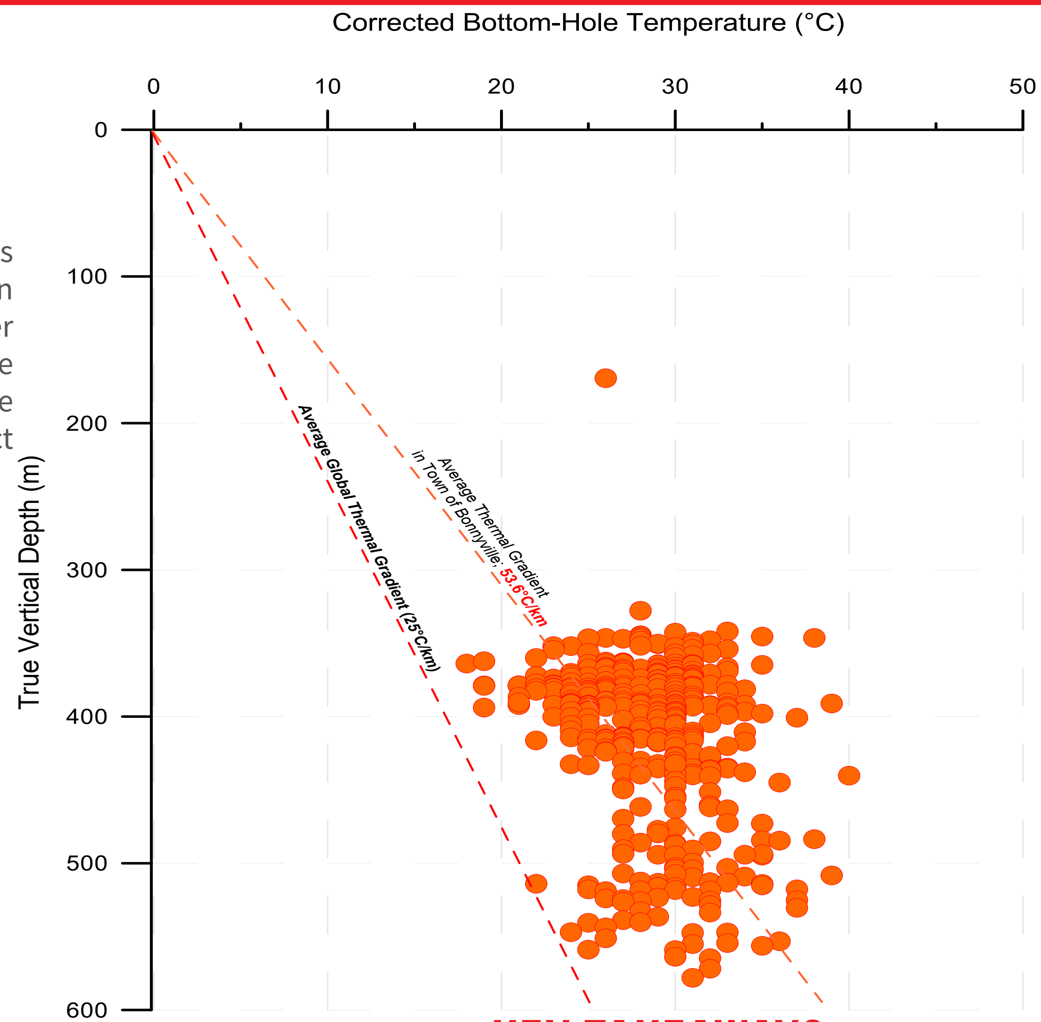
Corrected Bottom-Hole Temperature Map
(at Depths Greater than 500m - Town of Bonnyville)



RESEARCH RESULTS: BONNYVILLE

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 4 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Watt Mnt. (m)	Corrected Bottom-Hole Temperature (°C)	Expected Temperature at the Base of Target Formations. (°C)	Current Operator
100/10-04-061-05W4/00	1421.1	- 569.7	36	80	Bromley Marr Ecos Inc
100/10-11-060-06W4/00	588.9	19.2	26	60	Kissinger Petrls Ltd
100/14-15-060-05W4/00	577.9	148.7	32	60	Crescent Point Enrg Corp
100/10-21-060-05W4/00	571.7	142.5	31	60	Crescent Point Enrg Corp

KEY TAKEAWAYS

- The geothermal formation in your area is the **Watt Mountain** formation.
- The indicated geothermal gradient in your area is **53.6°C/km**, influenced by the shallowness of the study area's wells
- The majority of wells drilled in the study area are extremely shallow, drilled to less than **600mVd.**
- There is the potential for **geo-exchange** activities in the study area.

RECOMMENDATION & NOTES

Our study has uncovered a number of detrimental factors to geothermal development in the area. The only recorded geothermal formation in the study area, Watt Mountain, is shallow, very thin (3.7m thick) and unlikely able to sustain direct use activities. As well, the majority of wells in the region are also drilled to extremely shallow depths. This lack of drilled depth compounds potentially anomalous temperature readings, improper measurement gathering, and/or data entry errors and can lead to a severe overestimation of the temperature potential. The bottom hole temperature of the deepest well is only 36C which indicates that the geothermal gradient is influenced by these factors. It is recommended that Bonnyville investigate the opportunity to build geo-exchange systems to take advantage of the relatively stable temperature below the frostline.

September 25, 2018

Geothermal Analysis

Fairview

Study by Terrapin Geothermics

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above 0^{o}C.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

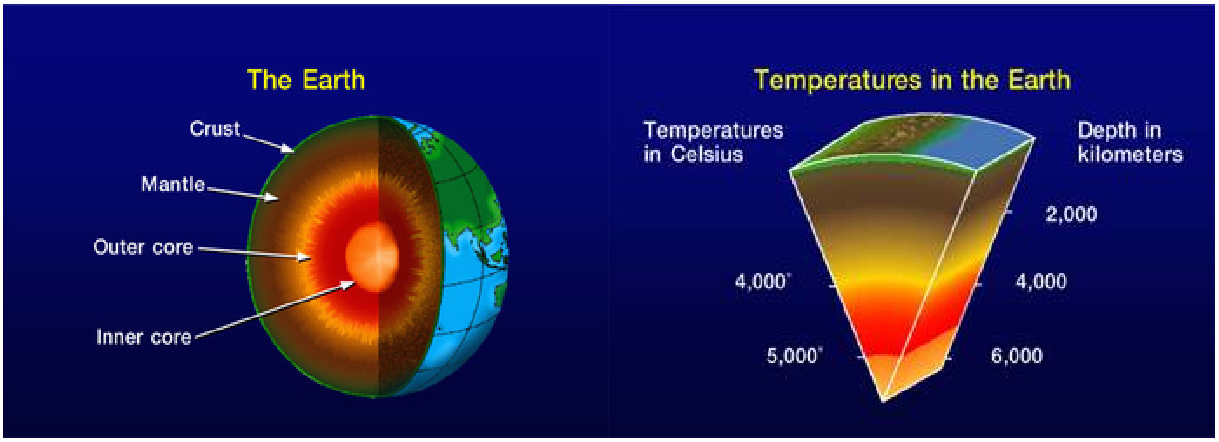
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

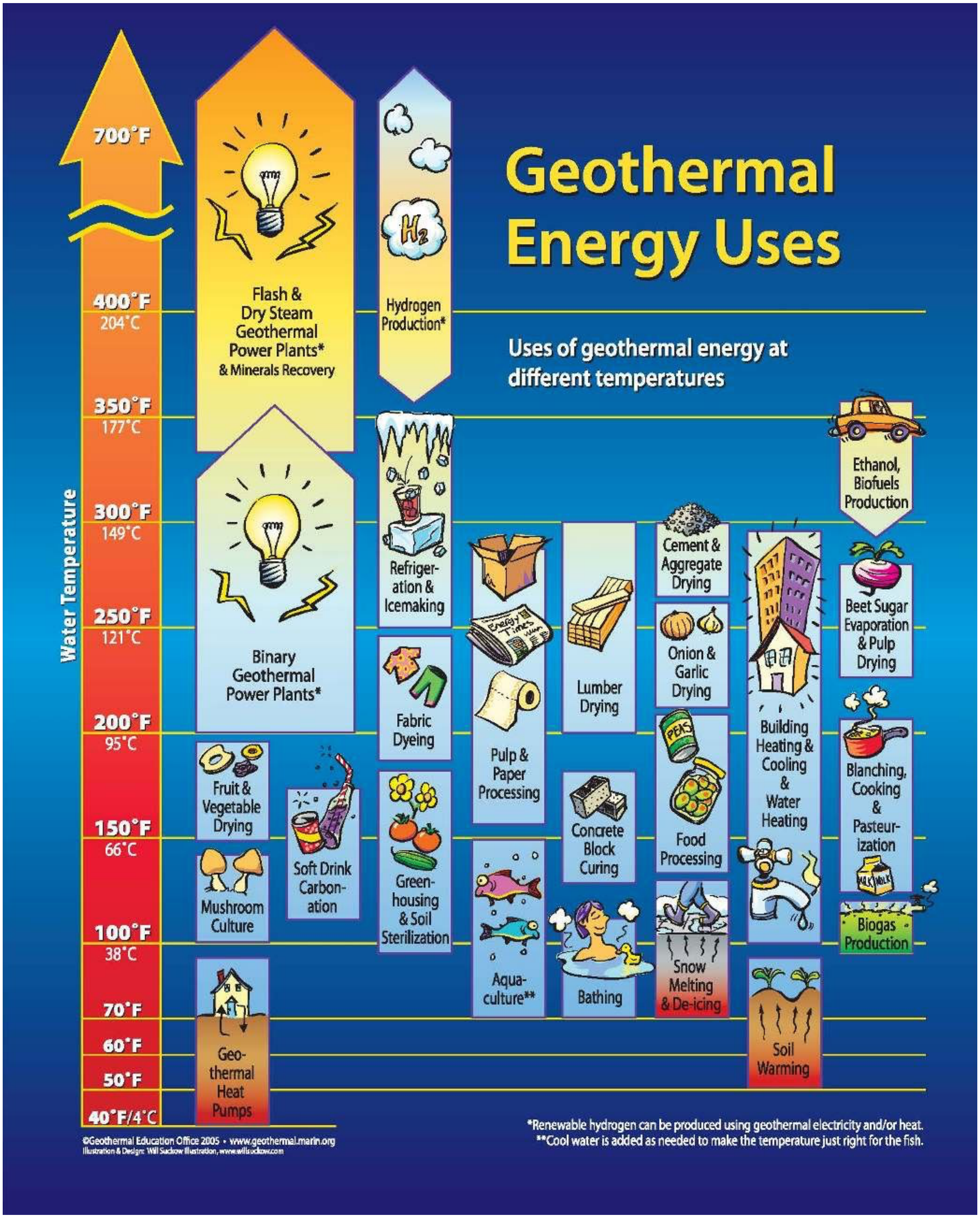
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160^{o}C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180°C and above), medium (100-180°C), and low (80-100°C) temperature resources with fluids under 80°C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235°C or above); flash plants (turning geothermal fluids of at least 150°C into steam to drive a turbine); and binary power plants (using hot waters above 80°C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180°C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

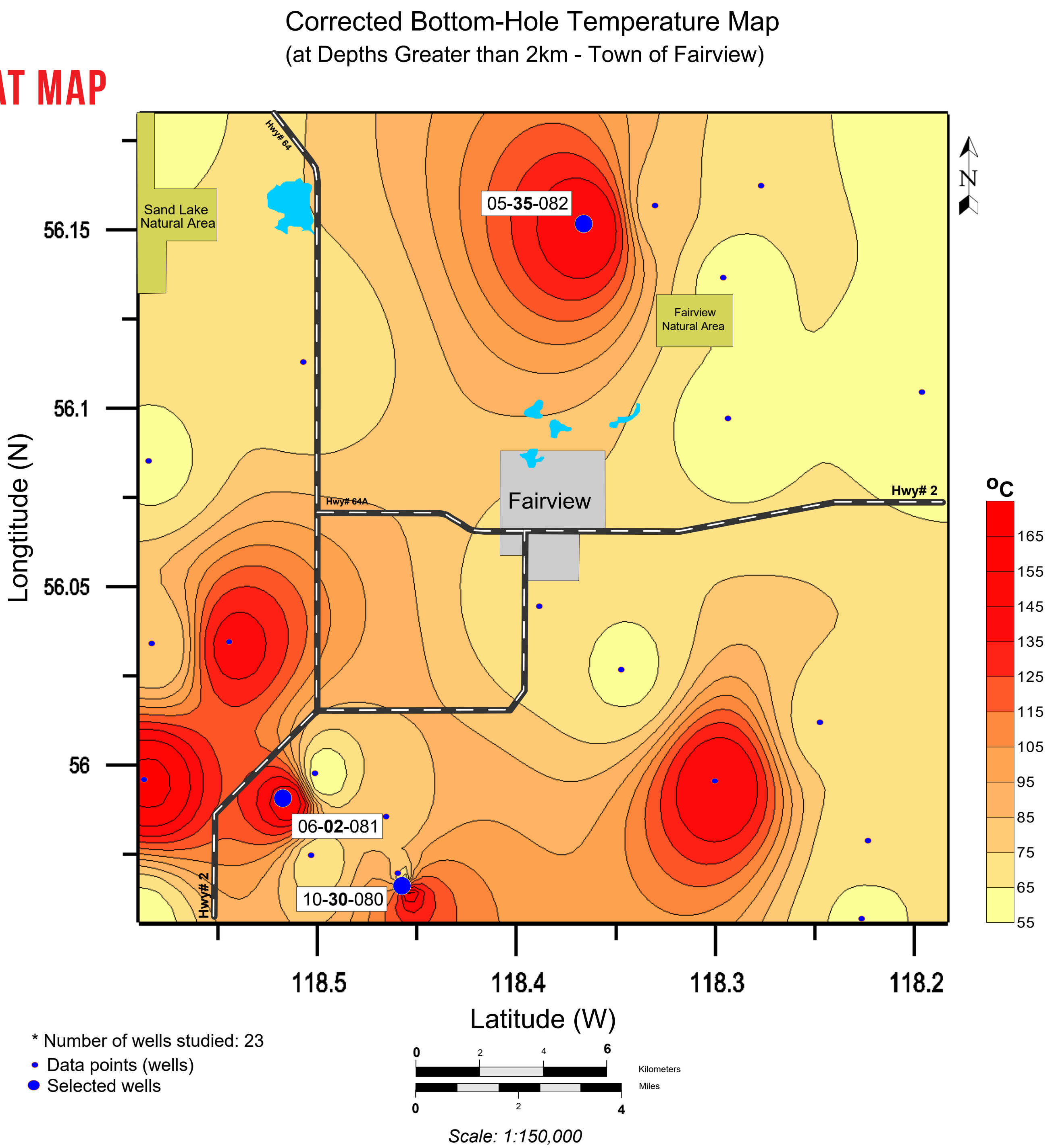
The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

RESEARCH RESULTS: FAIRVIEW

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

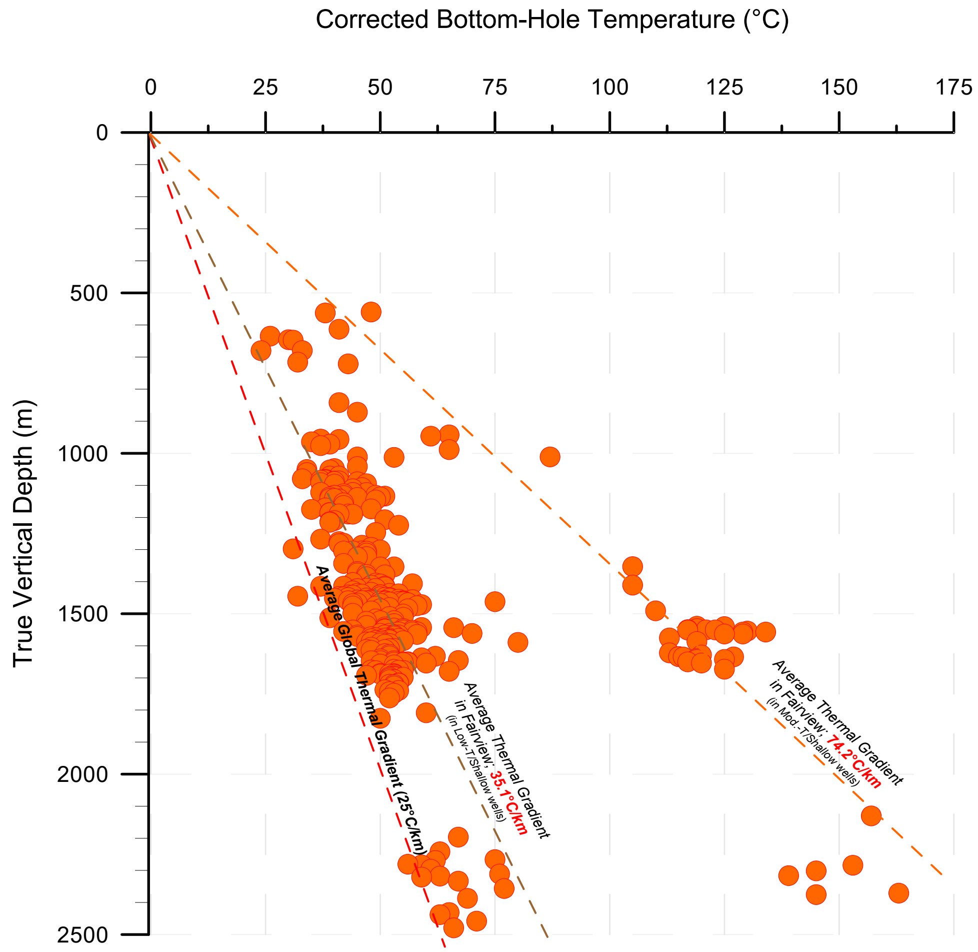
HEAT MAP



RESEARCH RESULTS: FAIRVIEW

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 3 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Granite Wash F. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/10-30-080-03W6/00	2370.1	-73.8	163	175	Transocean Oil Inc
100/06-02-081-04W6/00	2283.2	-15.2	153	175	Cdn Nat Rsrcs Ltd
100/05-35-082-03W6/00	2300.6	-46.6	145	150	177293 Cda Ltd

KEY TAKEAWAYS

- The potential geothermal reservoir underlying the study area is the **Granite Wash** formation.
- There are two temperature data sets in the study region. The low-moderate set has an average thermal gradient of **49.3ºC/km.**. The moderate-high set has an average thermal gradient of **74.2ºC/km**.
- There is strong potential for **direct-use** applications in the north and southwest of the study area.

RECOMMENDATION & NOTES

Our research work around Fairview identified two temperature data sets: a low-moderate grouping, at an average drilled depth of 1450m and a moderate-high temperature grouping at a depth of 1700m. These data sets indicate the strong potential for direct use applications in the study. It is strongly recommended that Fairview pursue further investigation into these temperature readings. Specific studies should seek to validate this initial temperature data, map fluid flows within target formations, and create detailed thermal energy potential models to provide a basis for understanding the heat-use opportunities for any future development activity in the area.

September 25, 2018

Geothermal Analysis

Grande Cache

Study by Terrapin Geothermics

For further information,
contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

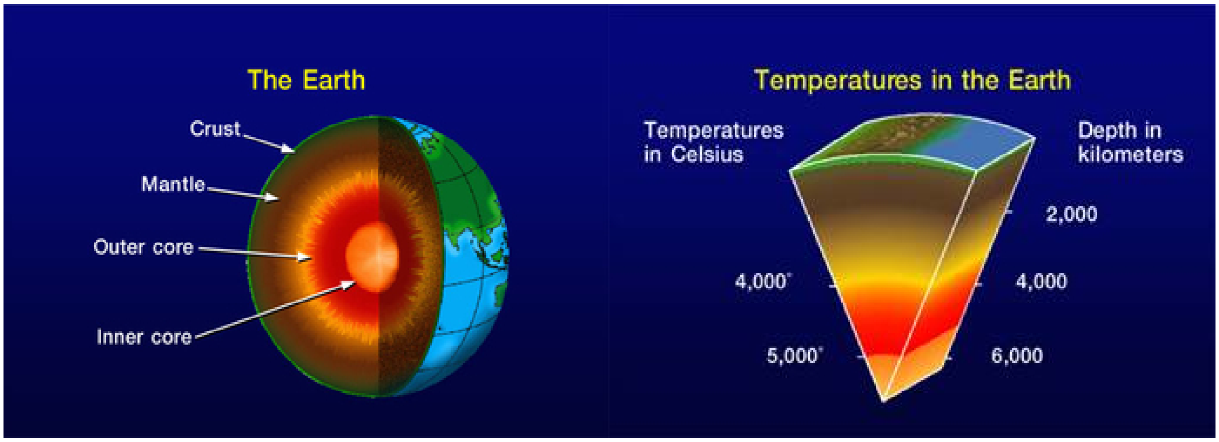
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

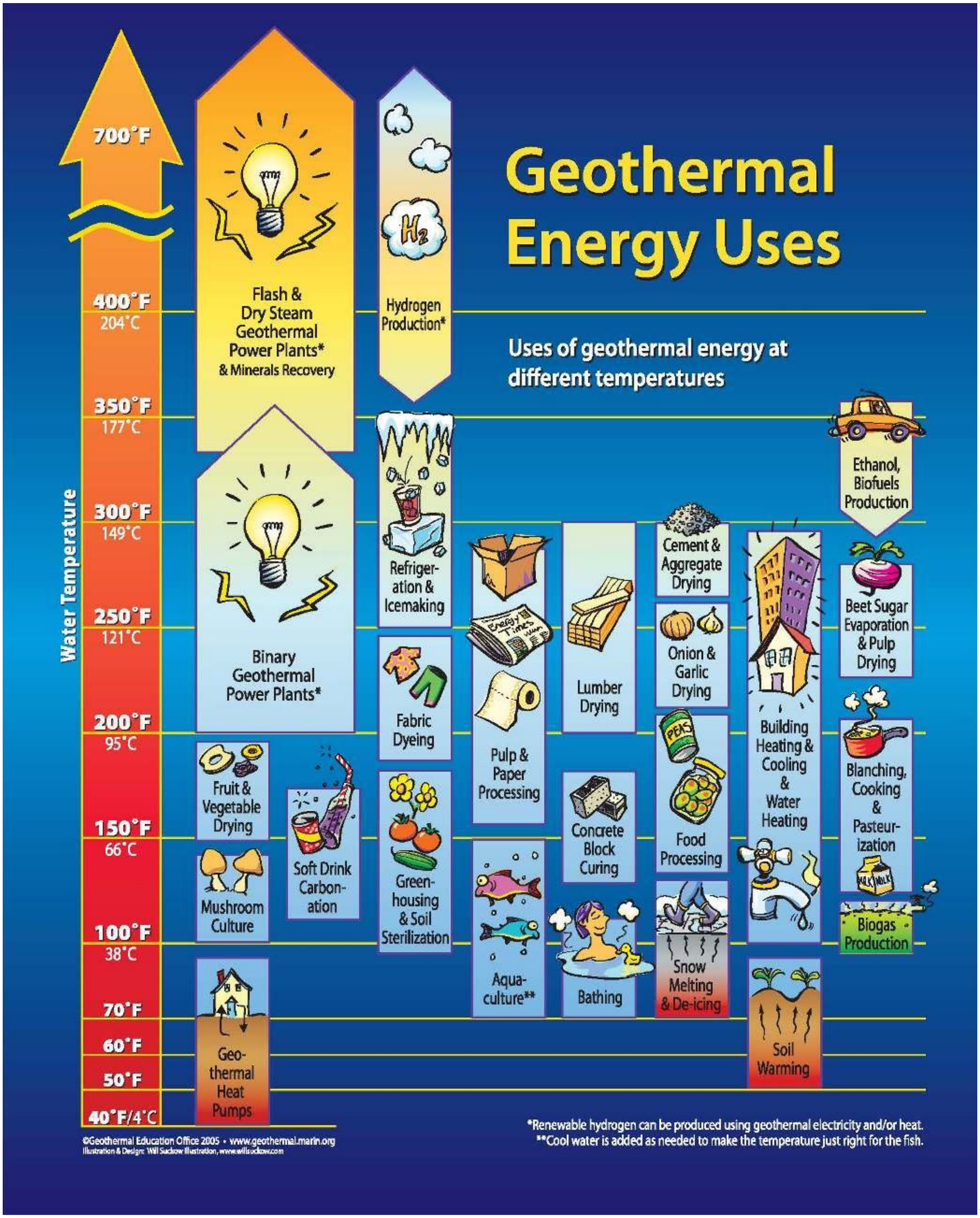
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180°C and above), medium (100-180°C), and low (80-100°C) temperature resources with fluids under 80°C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235°C or above); flash plants (turning geothermal fluids of at least 150°C into steam to drive a turbine); and binary power plants (using hot waters above 80°C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180°C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

terrapin

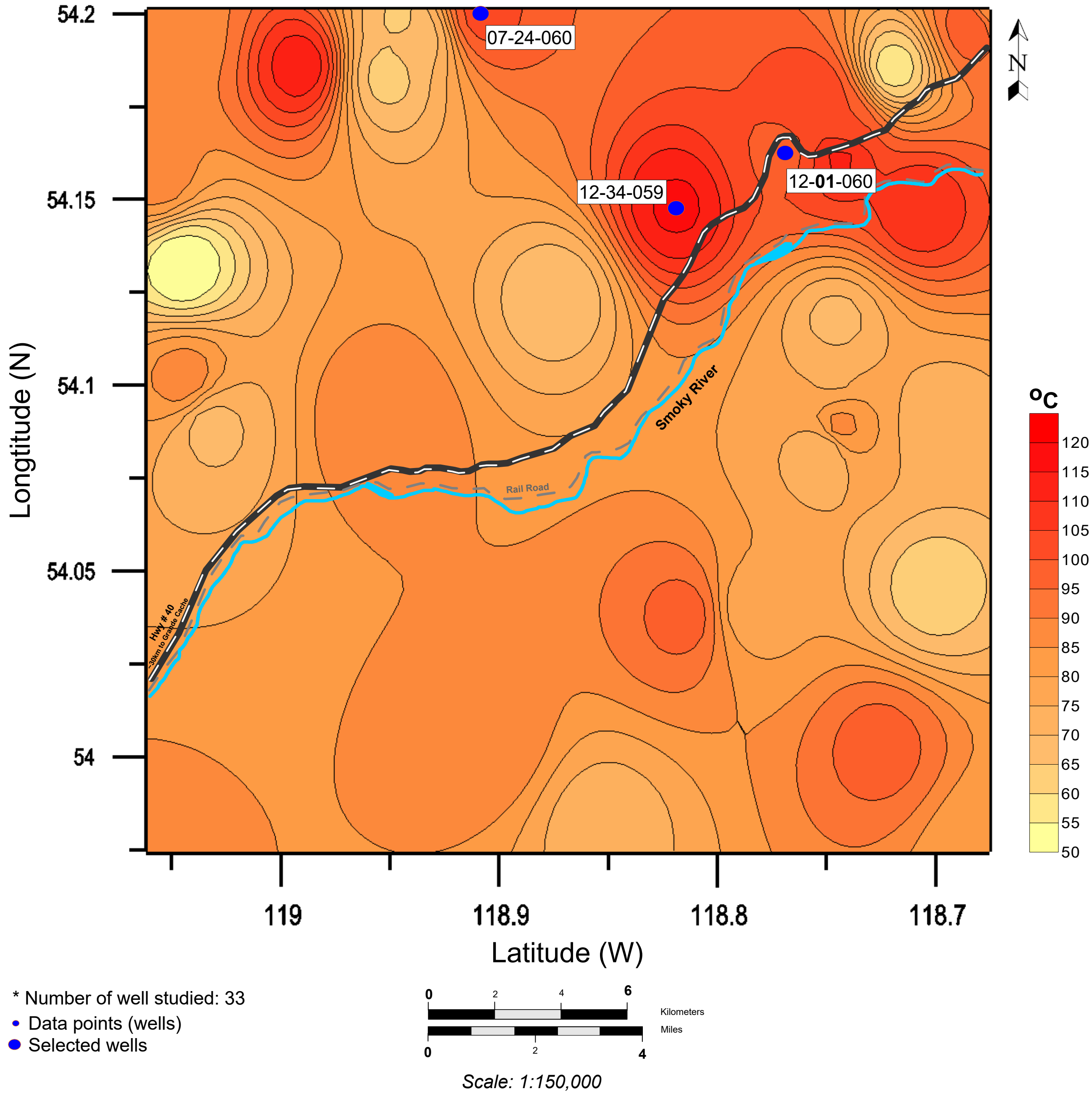
RESEARCH RESULTS: GRANDE CACHE

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

HEAT MAP

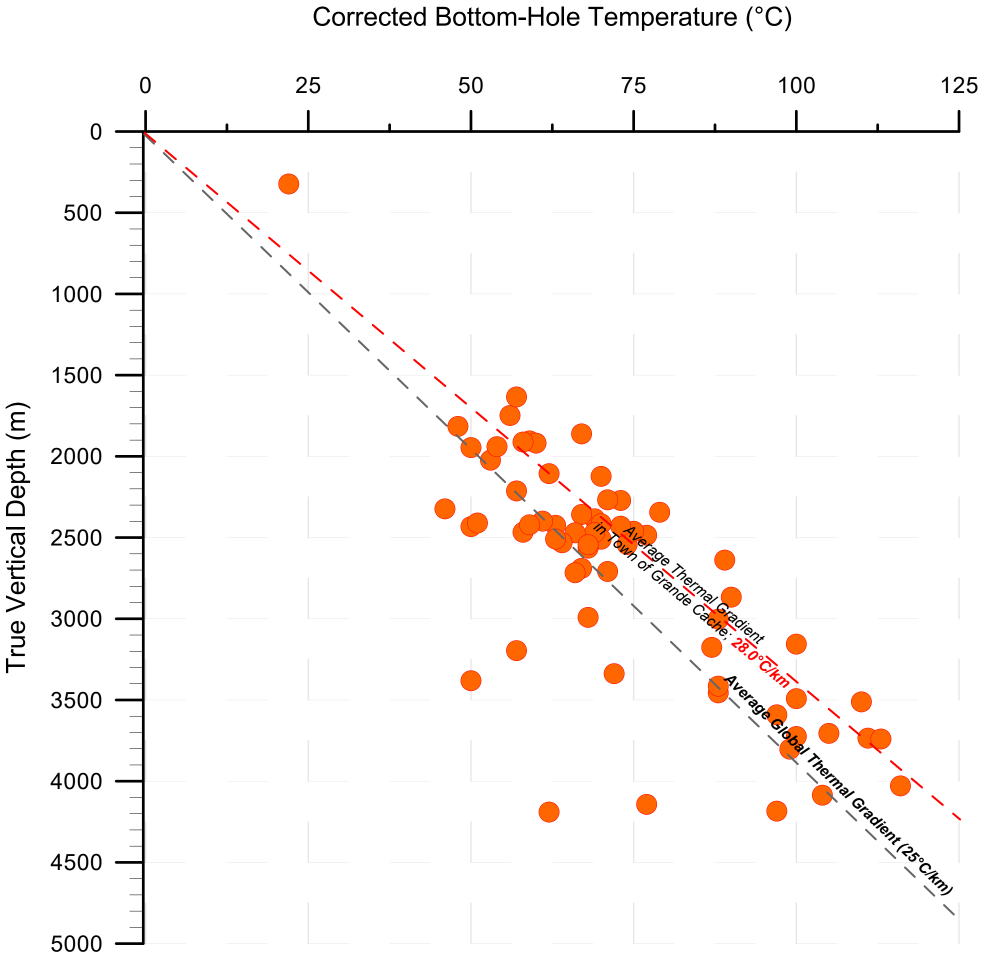
Corrected Bottom-Hole Temperature Map
(at Depths Greater than 2.5km - 15km NW of Town of Grande Cache)



RESEARCH RESULTS: GRANDE CACHE

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 3 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Gilwood M. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/07-24-060-07W6/00	4084.5	835.7	104	150	Plains Midstream Cda ULC
100/12-34-059-06W6/00	4027.3	892.9	116	160	BP Cda Enrg Grp ULC
100/12-01-060-06W6/00	3801.1	1119.1	99	140	BP Cda Enrg Grp ULC

KEY TAKEAWAYS

- The geothermal gradient in the study area is **28ºC/km**. This aligns with the global average.
- The geothermal formation in the study area is the **Gilwood member.** This formation occurred at **4920m** depth.
- Wells drilled in the study area are incredibly deep, many drilled between **1500m to 4500m**
- There is strong potential for **direct-use** applications in the study area.

RECOMMENDATION & NOTES

With the study area centered on the town of Grande Cache, there were no wells to utilize as data points and Terrapin is unable to make any general assumptions concerning the area. Therefore, the center point of the study was moved 40 km to the Northeast, with the edge of the study area located 15km from Grande Cache town center. There are a number of wells in the study area drilled deeper than 3000m providing consistently favourable temperature readings for direct use applications. Terrapin recommends that Grande Cache undertake targeted research that includes temperature validation activities, mapping the fluid flows within target formations, and creating detailed thermal energy potential models to provide a basis for understanding the heat-use opportunities in the area. This knowledge can provide direction for future land use planning and development activities.

September 25, 2018

Geothermal Analysis

Grimshaw

Study by Terrapin Geothermics

terrapin

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above 0^{o}C.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

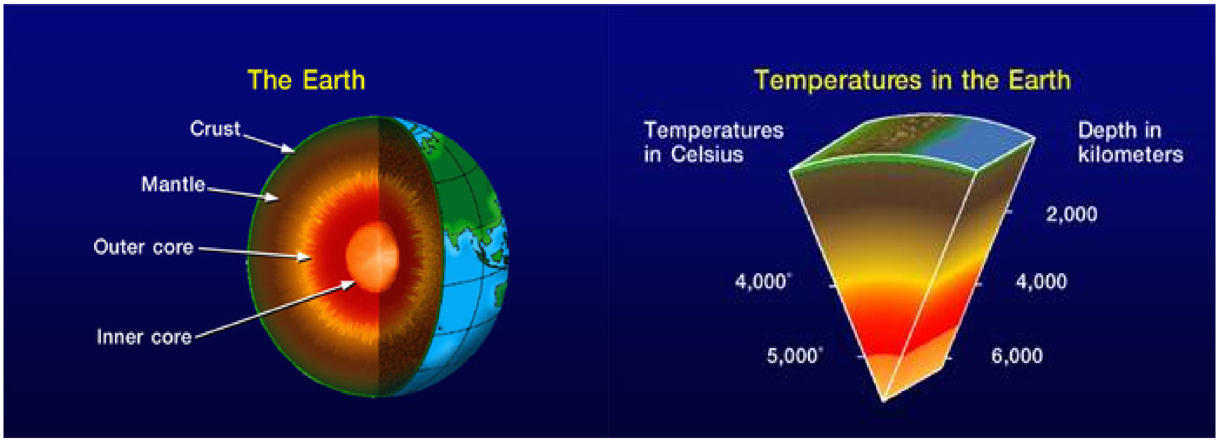
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

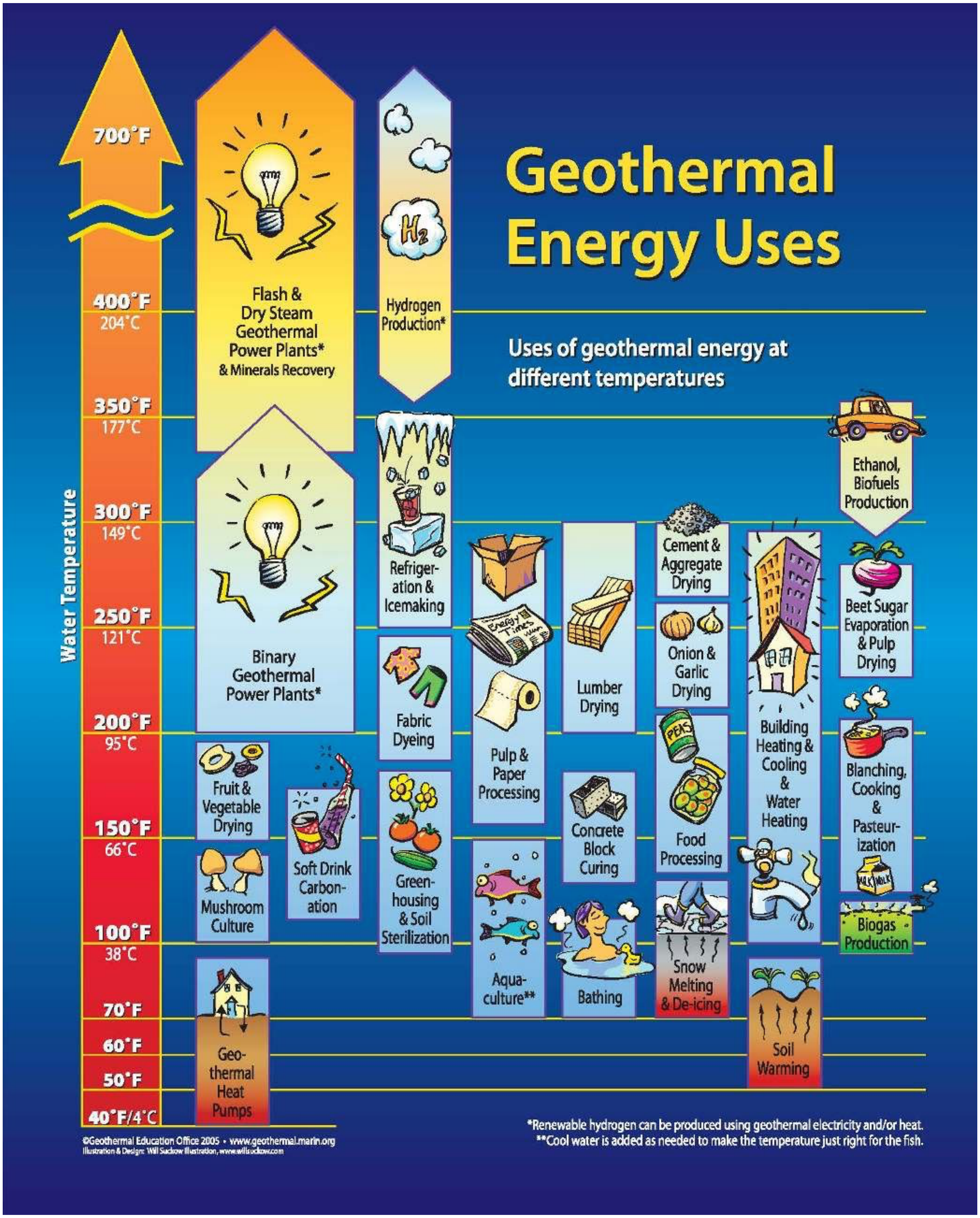
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160ºC and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180°C and above), medium (100-180°C), and low (80-100°C) temperature resources with fluids under 80°C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235°C or above); flash plants (turning geothermal fluids of at least 150°C into steam to drive a turbine); and binary power plants (using hot waters above 80°C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180°C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

---

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

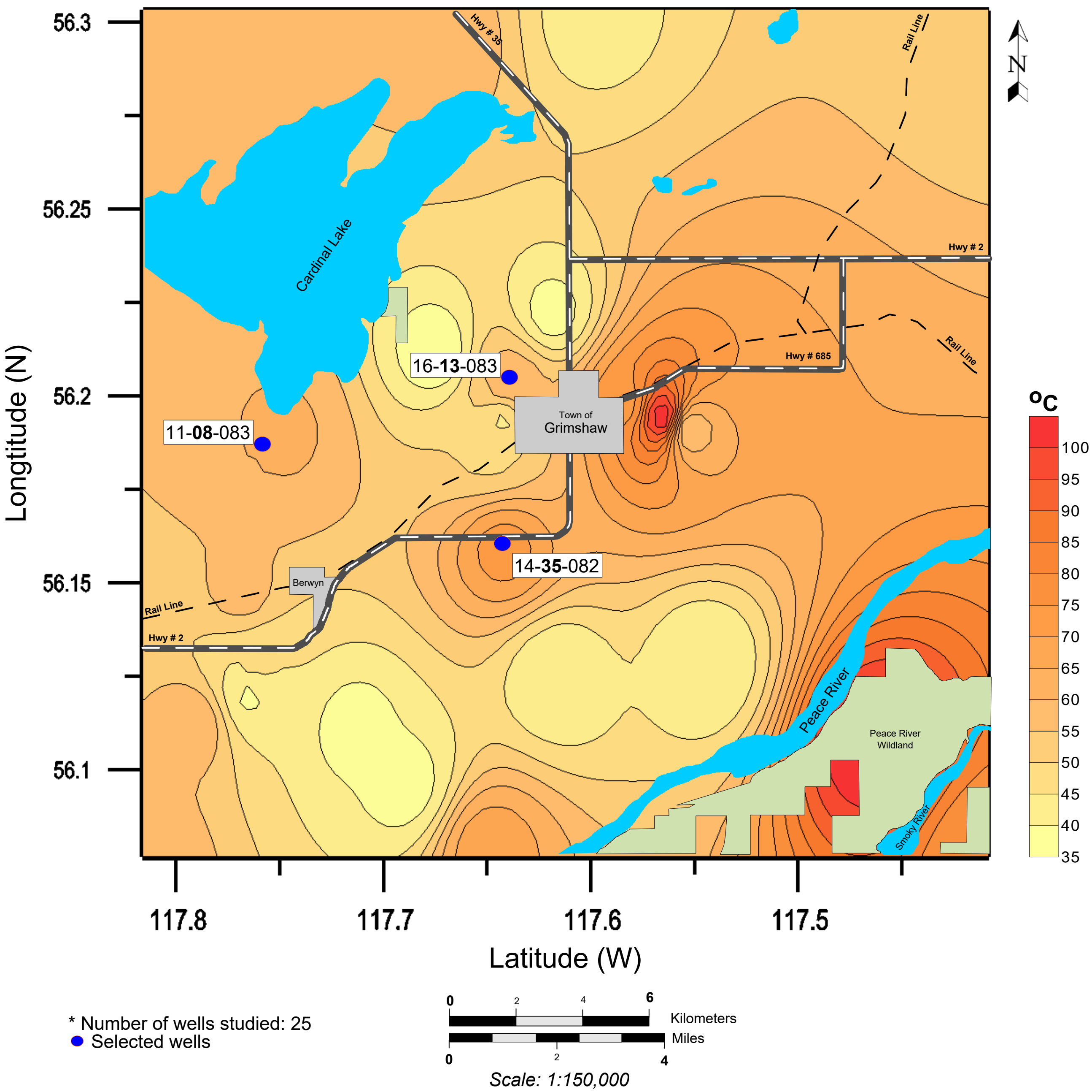
RESEARCH RESULTS: GRIMSHAW

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

HEAT MAP

Corrected Bottom-Hole Temperature Map
(at Depths Greater than 1 km - Town of Grimshaw)

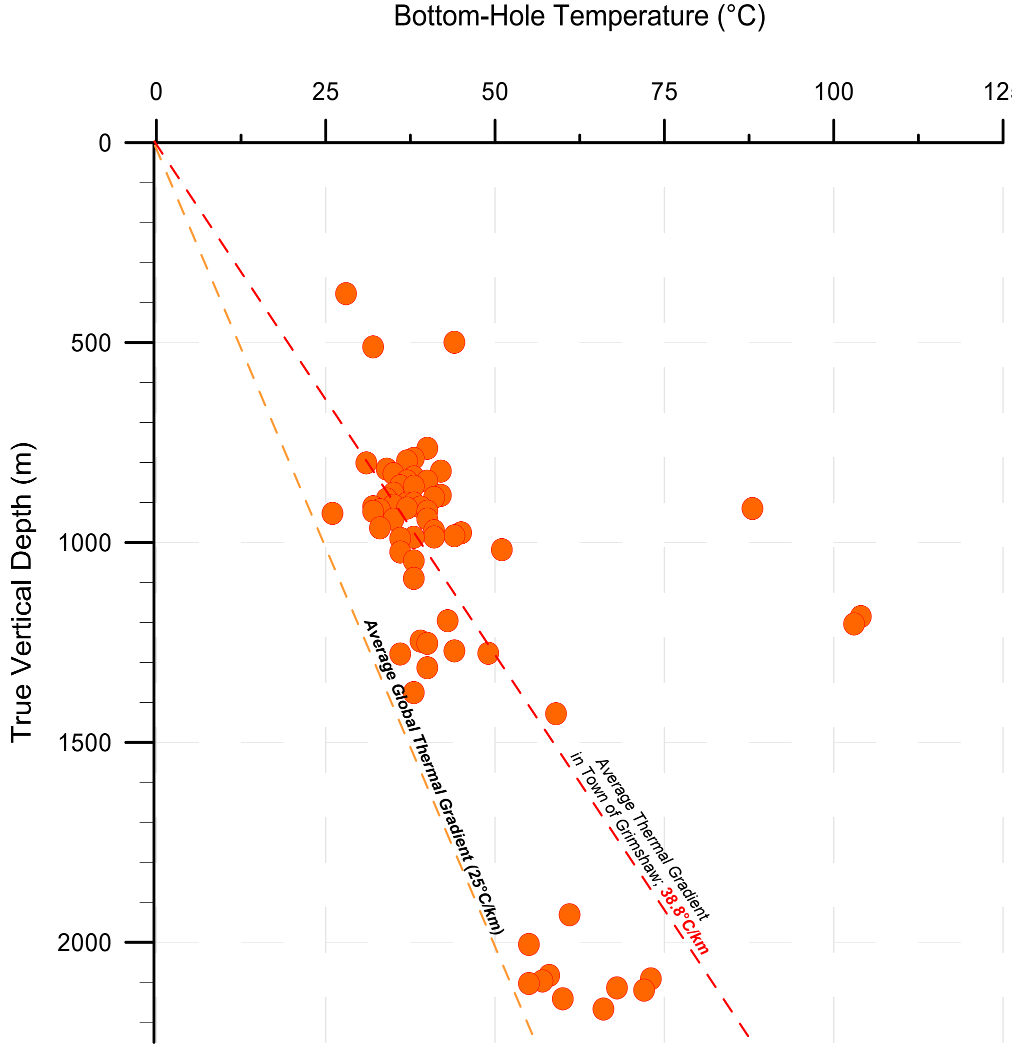


* Number of wells studied: 25
Selected wells

RESEARCH RESULTS: GRIMSHAW

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 3 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Leduc F. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/14-35-082-24W5/00	2123	-16.2	72	75	Cenovus Enrg Inc
100/11-08-083-24W5/00	2144.3	-25.9	60	70	BP Cda Enrg Grp ULC
100/16-13-083-24W5/00	2169.3	-53.4	66	70	BP Cda Enrg Grp ULC

KEY TAKEAWAYS

- There are two likely productive geothermal formations underlying the study area: the **Leduc** and the **Granite Wash** formations.
- The geothermal gradient in the study area is
- **38.8ºC/km**. This is **55% higher** than the global average.
- There is potential for **geo-exchange** opportunities in your region.

RECOMMENDATION & NOTES

Our initial study of the town of Grimshaw has uncovered geological phenomenon that are detrimental to geothermal development. The two productive geothermal formations in the study area are relatively thin, 50m and 24m thick, and may not be able to support direct use activities. As well, though there are a small number of higher bottom hole temperature readings in wells to the east of the town and drilled to 1250m depth, the low bottom hole temperatures of wells drilled to depths of more than 2km seem to invalidate these anomalous entries. It is recommended that the town of Grimshaw investigate the opportunity to build geo-exchange systems in order to take advantage of the relatively stable temperature below the frostline.

September 25, 2018

Geothermal Analysis

High Level

Study by Terrapin Geothermics

For further information,
contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above 0^oC.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

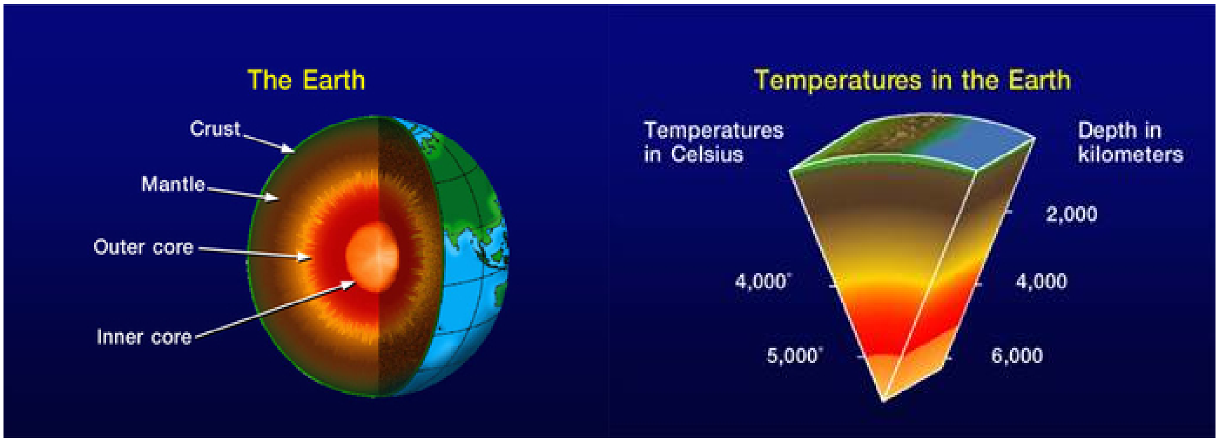
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

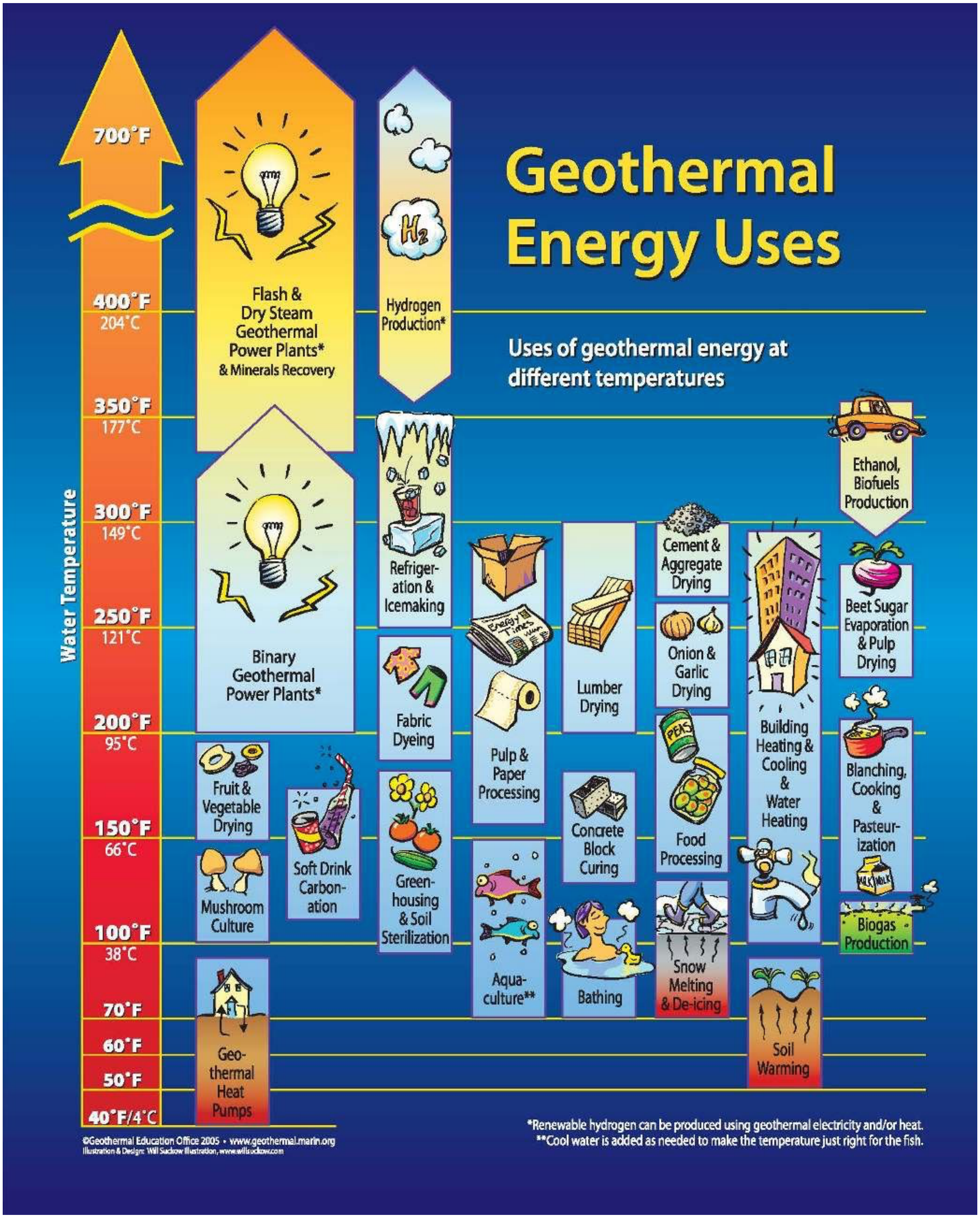
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180°C and above), medium (100-180°C), and low (80-100°C) temperature resources with fluids under 80°C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235°C or above); flash plants (turning geothermal fluids of at least 150°C into steam to drive a turbine); and binary power plants (using hot waters above 80°C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180°C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

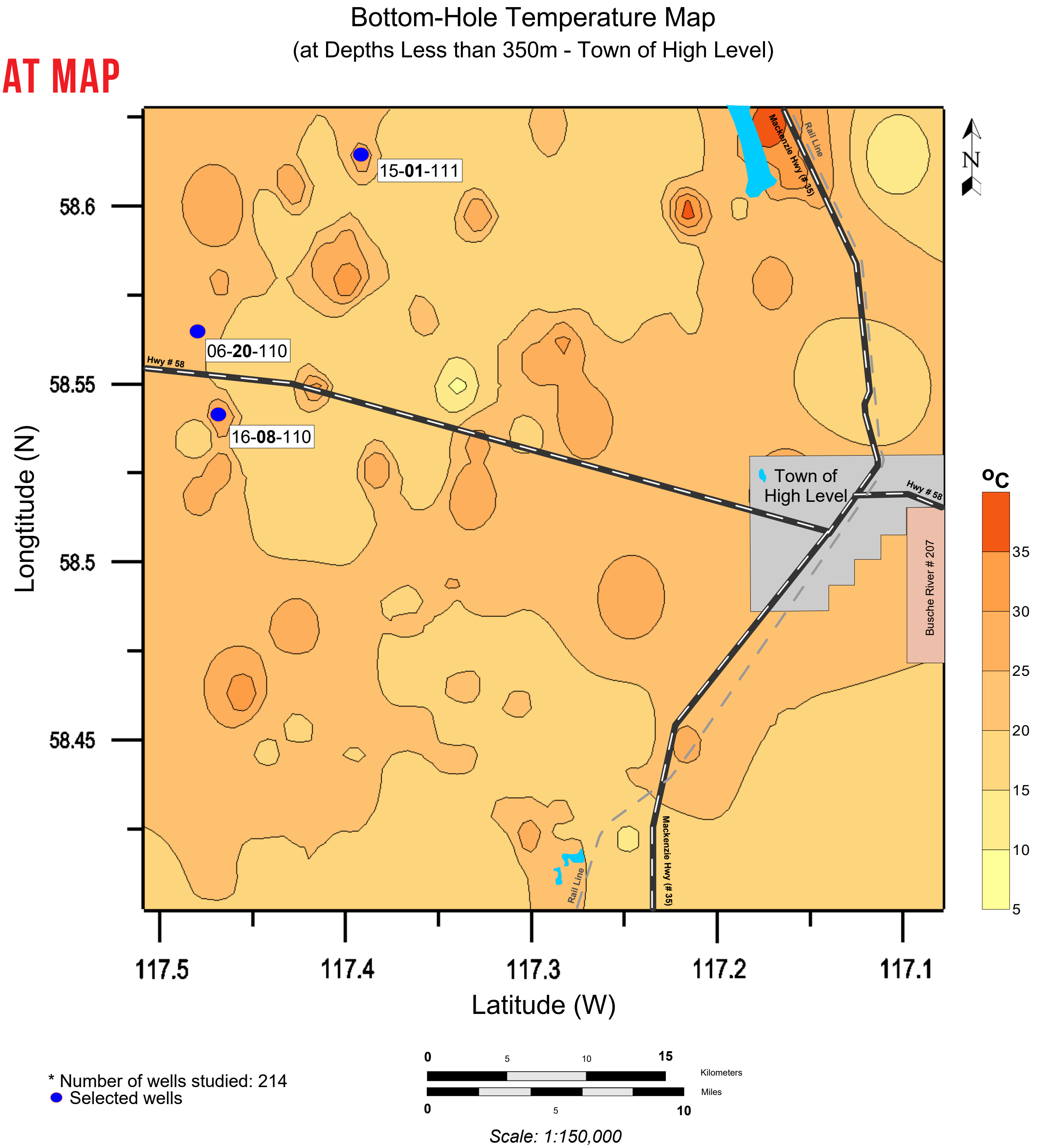
The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

RESEARCH RESULTS: HIGH LEVEL

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

HEAT MAP

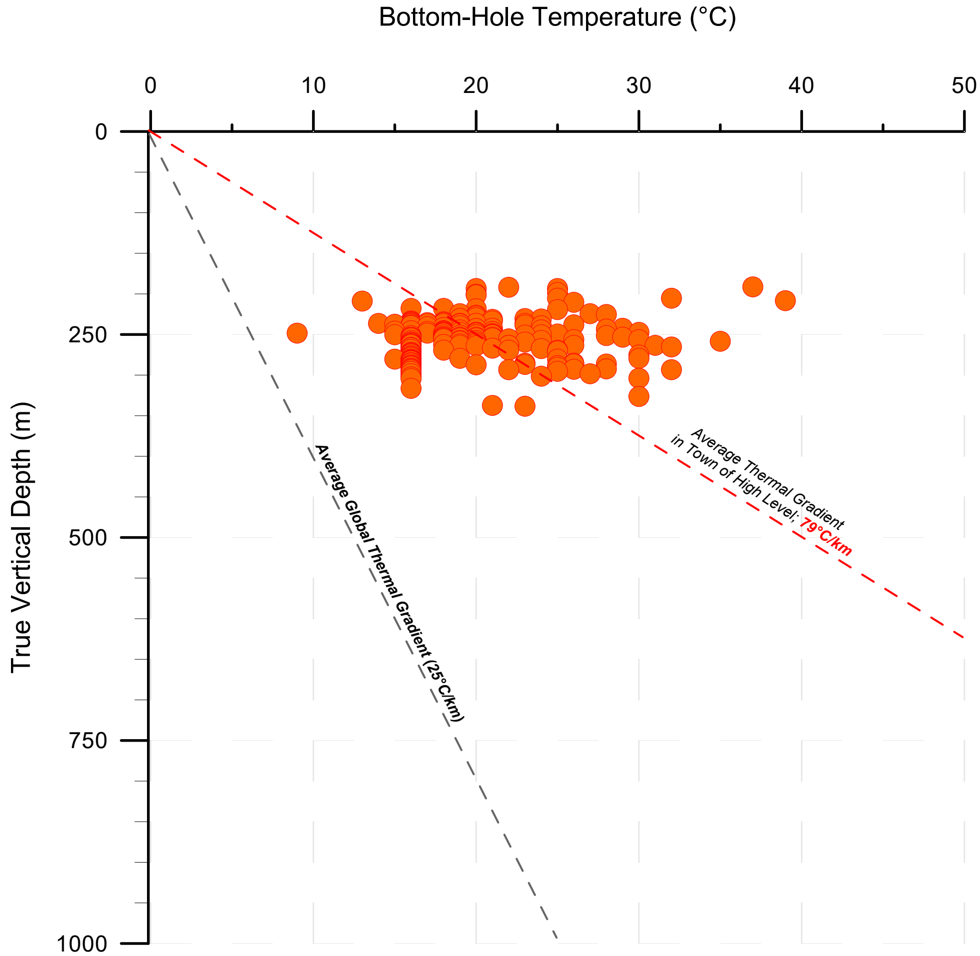


* Number of wells studied: 214
Selected wells

RESEARCH RESULTS: HIGH LEVEL

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 3 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Slave Point F. (m)	Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/15-01-111-21W5/00	298	907	27	135	Husky Oil Oprtns Ltd
100/06-20-110-21W5/00	301	904	24	120	Husky Oil Oprtns Ltd
100/16-08-110-21W5/00	303.5	901.5	30	150	Husky Oil Oprtns Ltd

KEY TAKEAWAYS

- The potential geothermal formation underlying the study area is the **Slave Point** formation
- The indicated geothermal gradient in your area is **79ºC/km**, likely influenced by the shallowness of the study area's wells.
- The wells in the study area are incredibly shallow, with drilled depths of less than **350m**
- There is potential for **geo-exchange** activities in your region

RECOMMENDATION & NOTES

The wells surrounding the town of High Level are incredibly shallow and provide little temperature or geological data that can be used to make accurate geothermal assumptions. It is likely that the geothermal gradient in the area is lower than indicated. A lack of drilled depth compounds potentially anomalous results, improper measurement gathering, or data entry errors and can lead to a severe overestimation of the temperature potential. We recommend that the Town conduct geological investigations to understand the localized subsurface processes occurring in the study area. In the interim, it is recommended that the Town investigate the opportunity to build geo-exchange systems to take advantage of the relatively stable temperature below the frostline.

September 25, 2018

Geothermal Analysis

High Prairie

Study by Terrapin Geothermics

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above 0°C.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

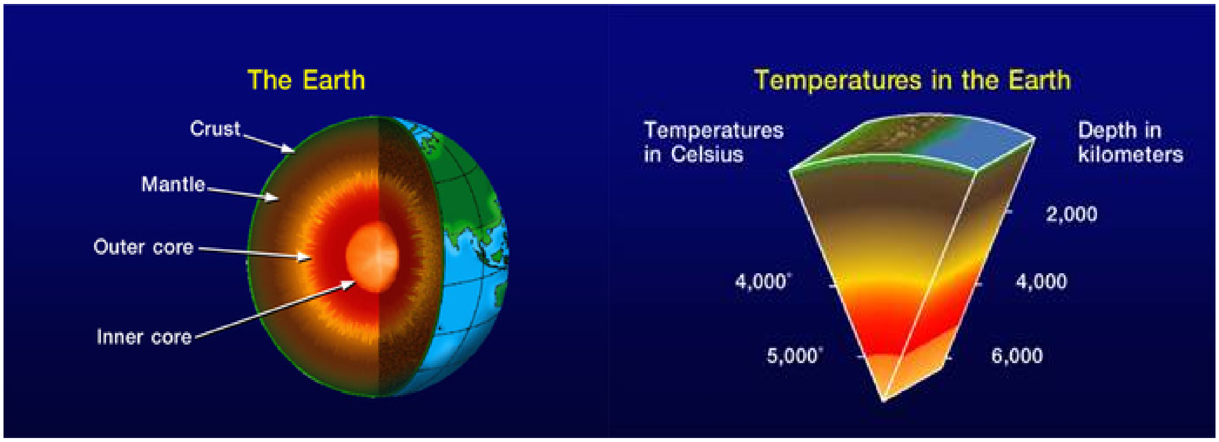
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

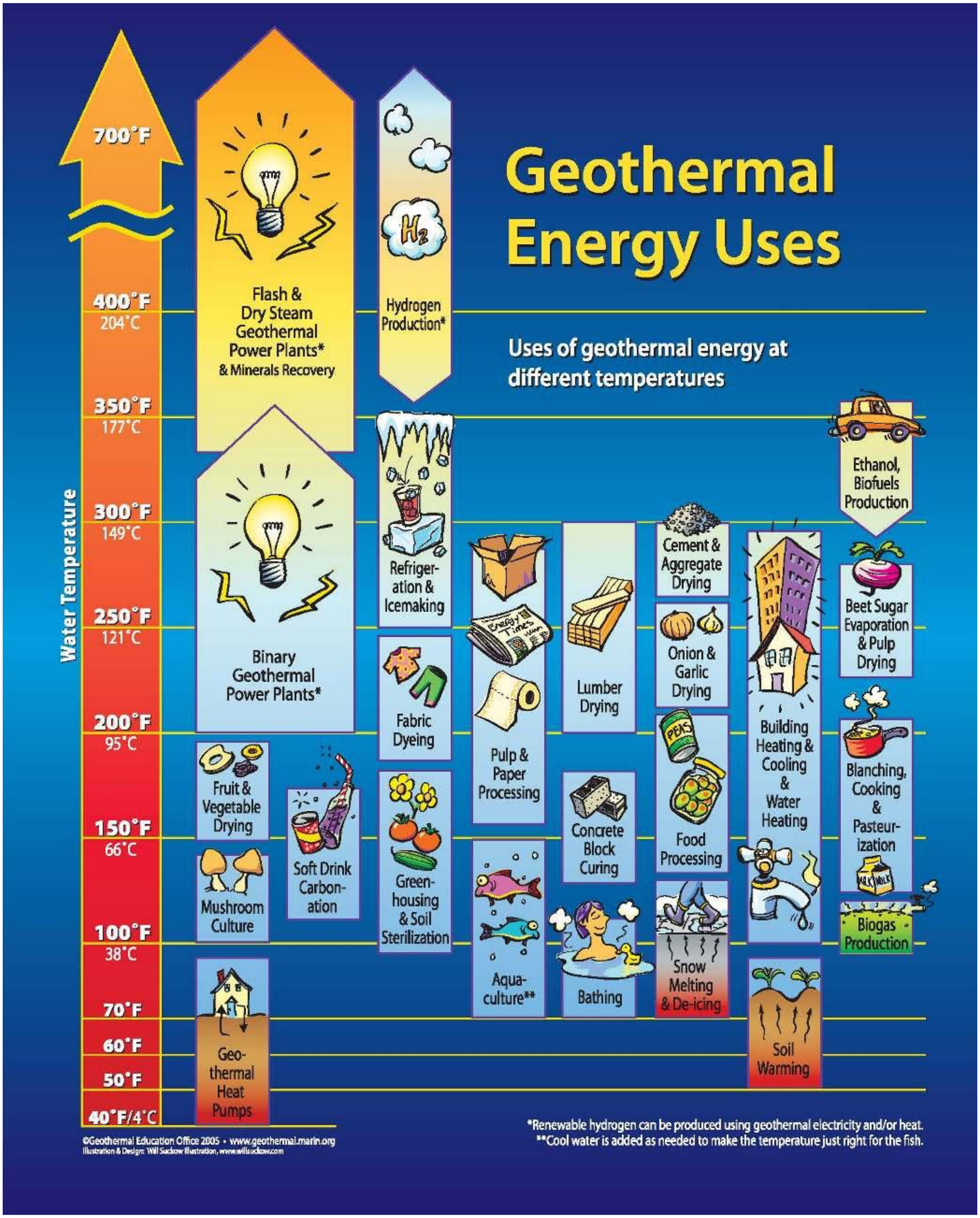
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180^{o}C and above), medium (100-180^{o}C), and low (80-100^{o}C) temperature resources with fluids under 80^{o}C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235^{o}C or above); flash plants (turning geothermal fluids of at least 150^{o}C into steam to drive a turbine); and binary power plants (using hot waters above 80^{o}C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180^{o}C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

RESEARCH RESULTS: HIGH PRAIRIE

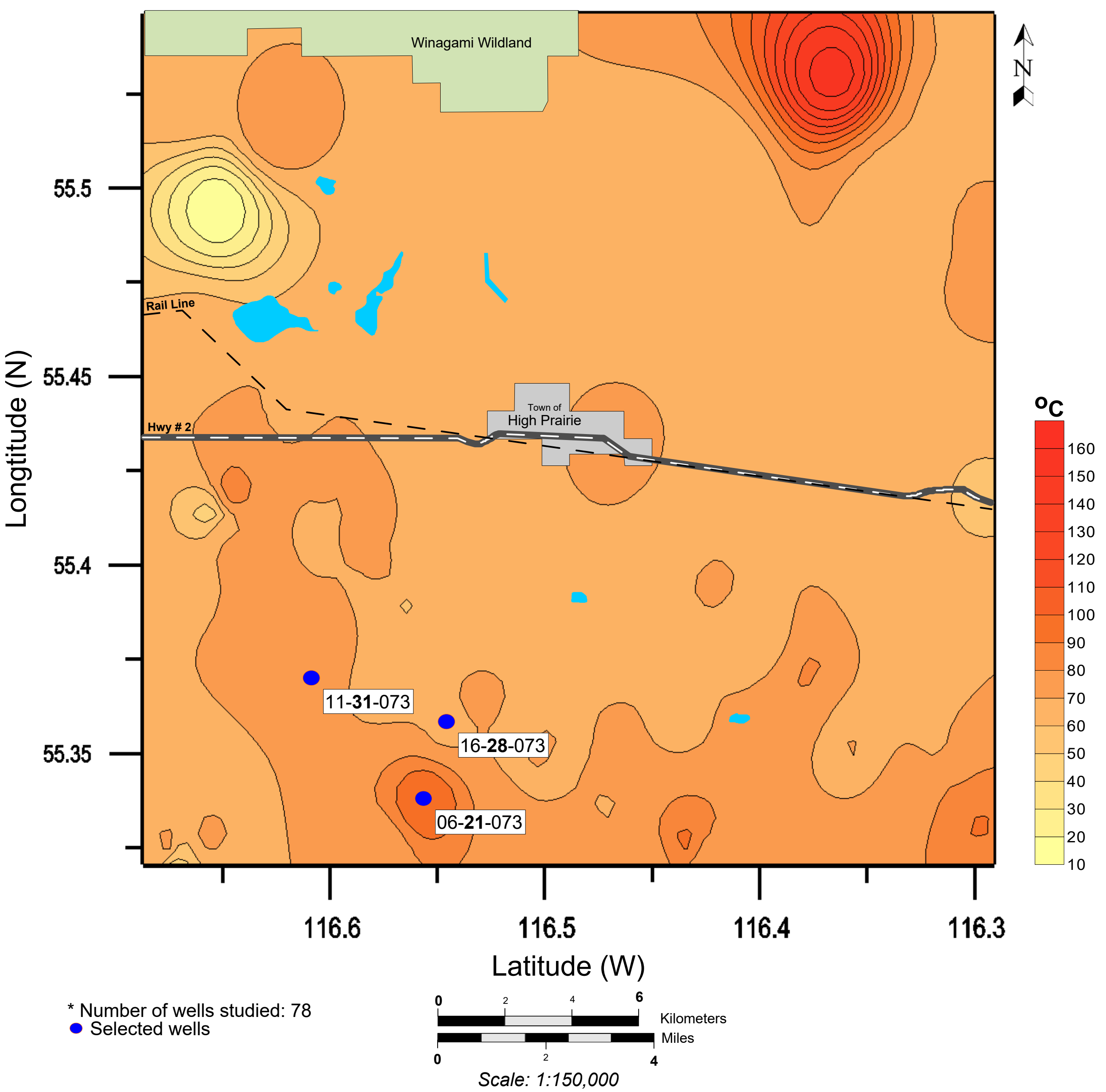
CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

HEAT MAP

Corrected Bottom-Hole Temperature Map

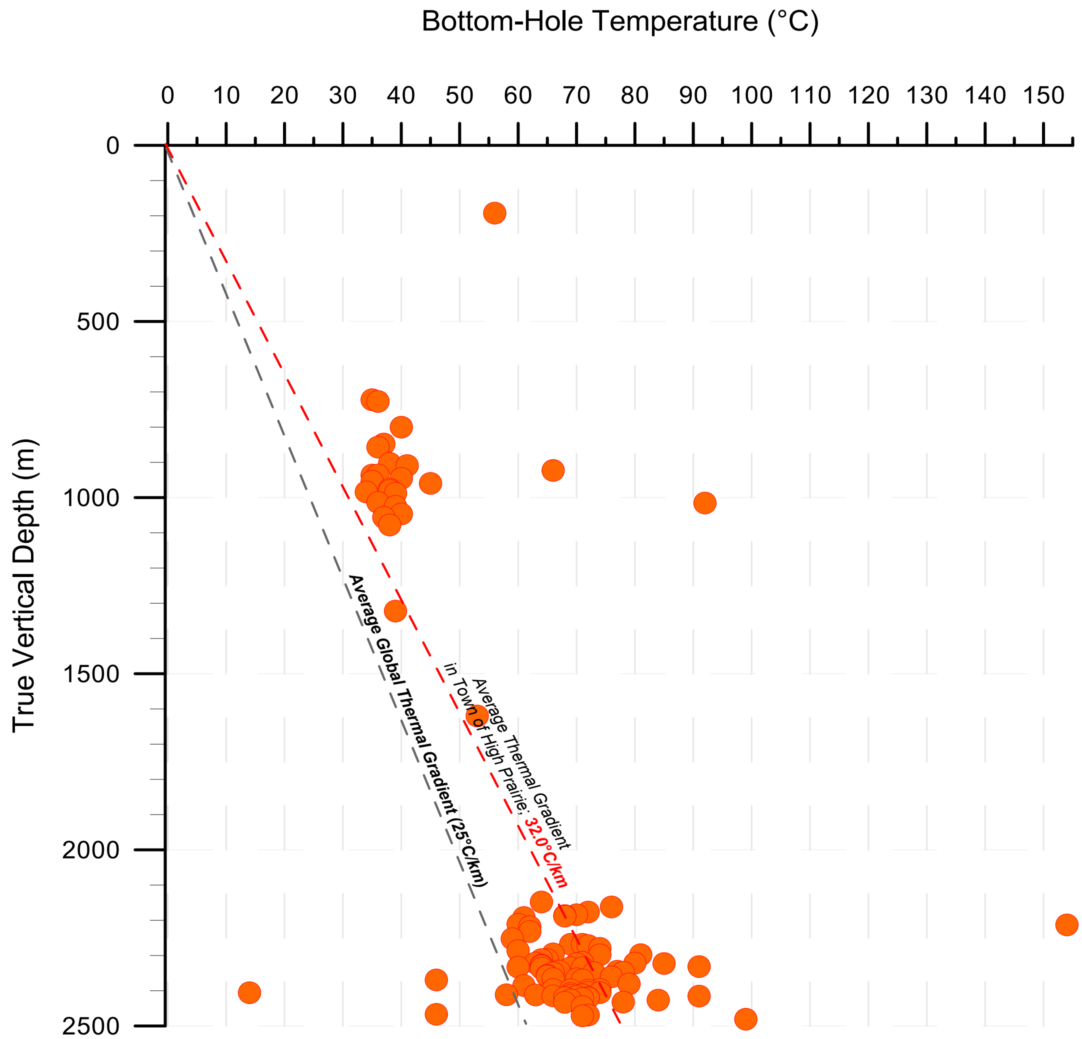
(at Depths Greater than 2 km - Town of High Prairie)



RESEARCH RESULTS: HIGH PRAIRIE

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 3 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation- Gilwood M. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/06-21-073-17W5/00	2480	-132.5	99	100	ARC Rsrcs Ltd
100/11-31-073-17W5/00	2444.2	-98.5	71	75	Cdn Nat Rsrcs Ltd
100/16-28-073-17W5/00	2432.2	-111	68	75	Cdn Nat Rsrcs Ltd

KEY TAKEAWAYS

- The productive geothermal formations underlying the study area are the **Gilwood** member and the **Granite Wash** formation.
- The temperature gradient in the study area is **31.8°C/km**. This aligns closely with the global average.
- There is potential for **geo-exchange** and possible **direct-use** activities in the study area.

RECOMMENDATION & NOTES

Our study of the town of High Prairie has identified an average geothermal resource underlying the town and surrounding area. The identified geothermal formations have a thickness of 70m and, other than a single anomalous reading in the northeast of the study area, the registered bottom hole temperatures of the majority of wells are at the temperature threshold for direct-use activities. Further investigations into direct-use development opportunities, particularly to the northeast of High Prairie is suggested. In the interim, it is recommended that the town investigate the opportunity to build geo-exchange systems to take advantage of the relatively stable temperature below the frostline.

September 25, 2018

Geothermal Analysis

Manning

Study by Terrapin Geothermics

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above 0^{o}C.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

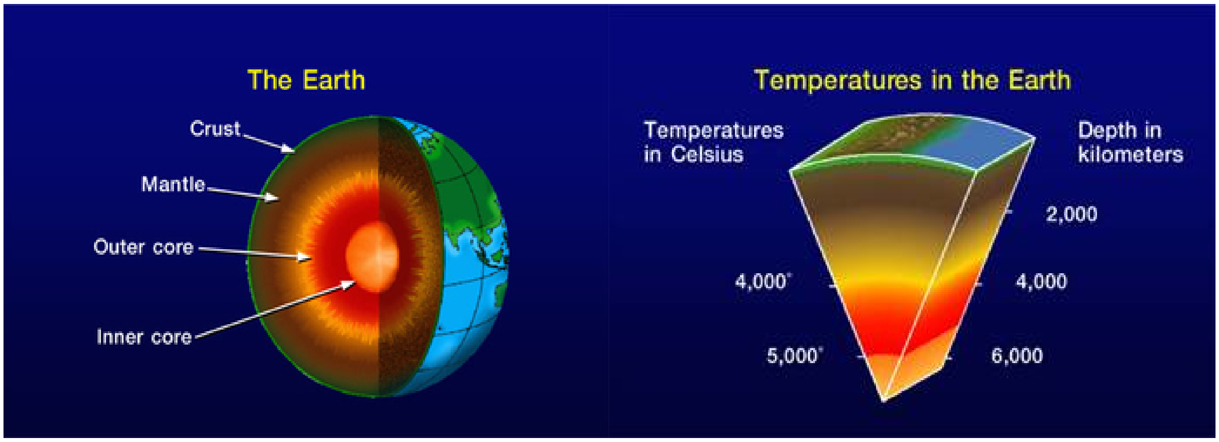
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

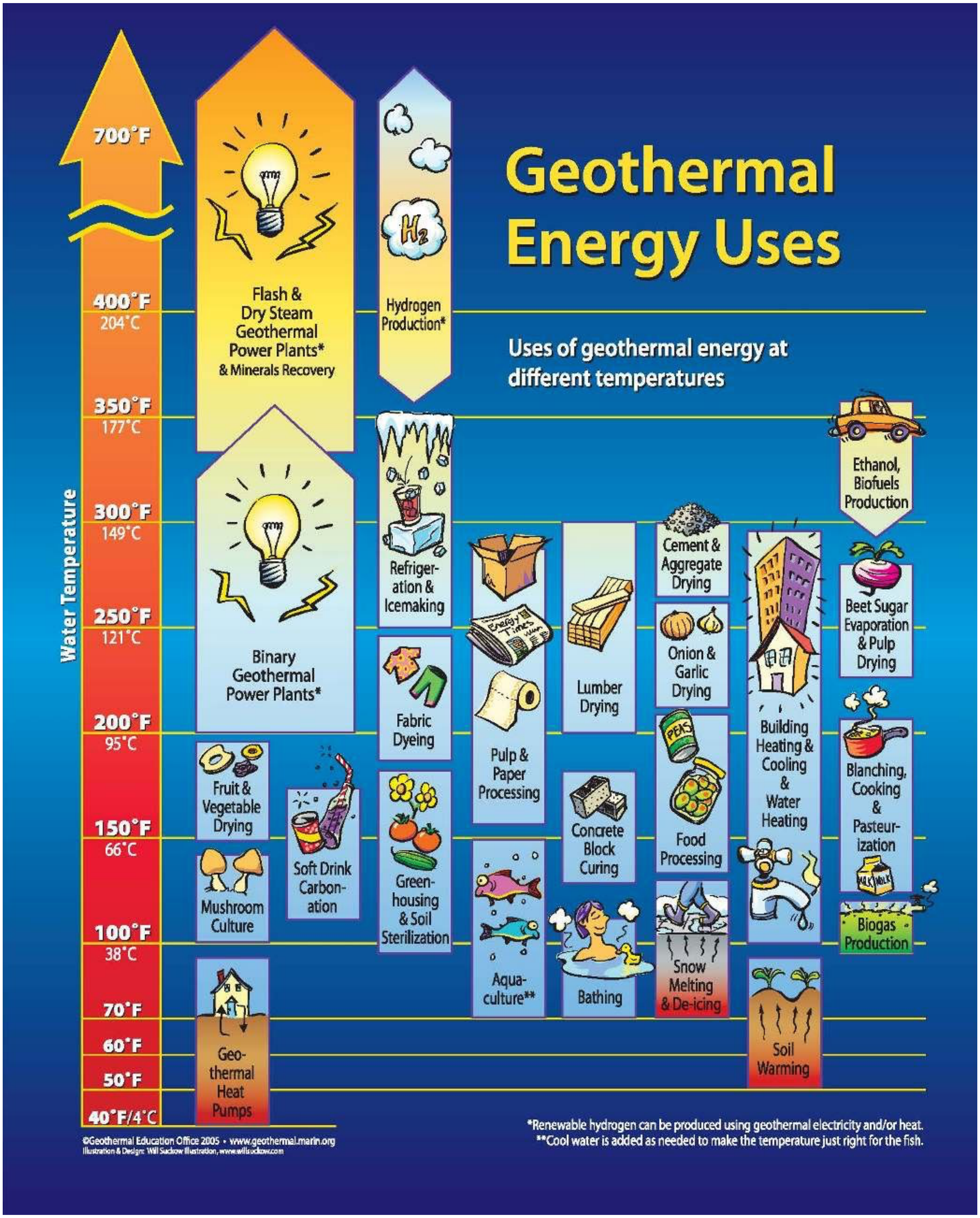
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180^{o}C and above), medium (100-180^{o}C), and low (80-100^{o}C) temperature resources with fluids under 80^{o}C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235^{o}C or above); flash plants (turning geothermal fluids of at least 150^{o}C into steam to drive a turbine); and binary power plants (using hot waters above 80^{o}C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180^{o}C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

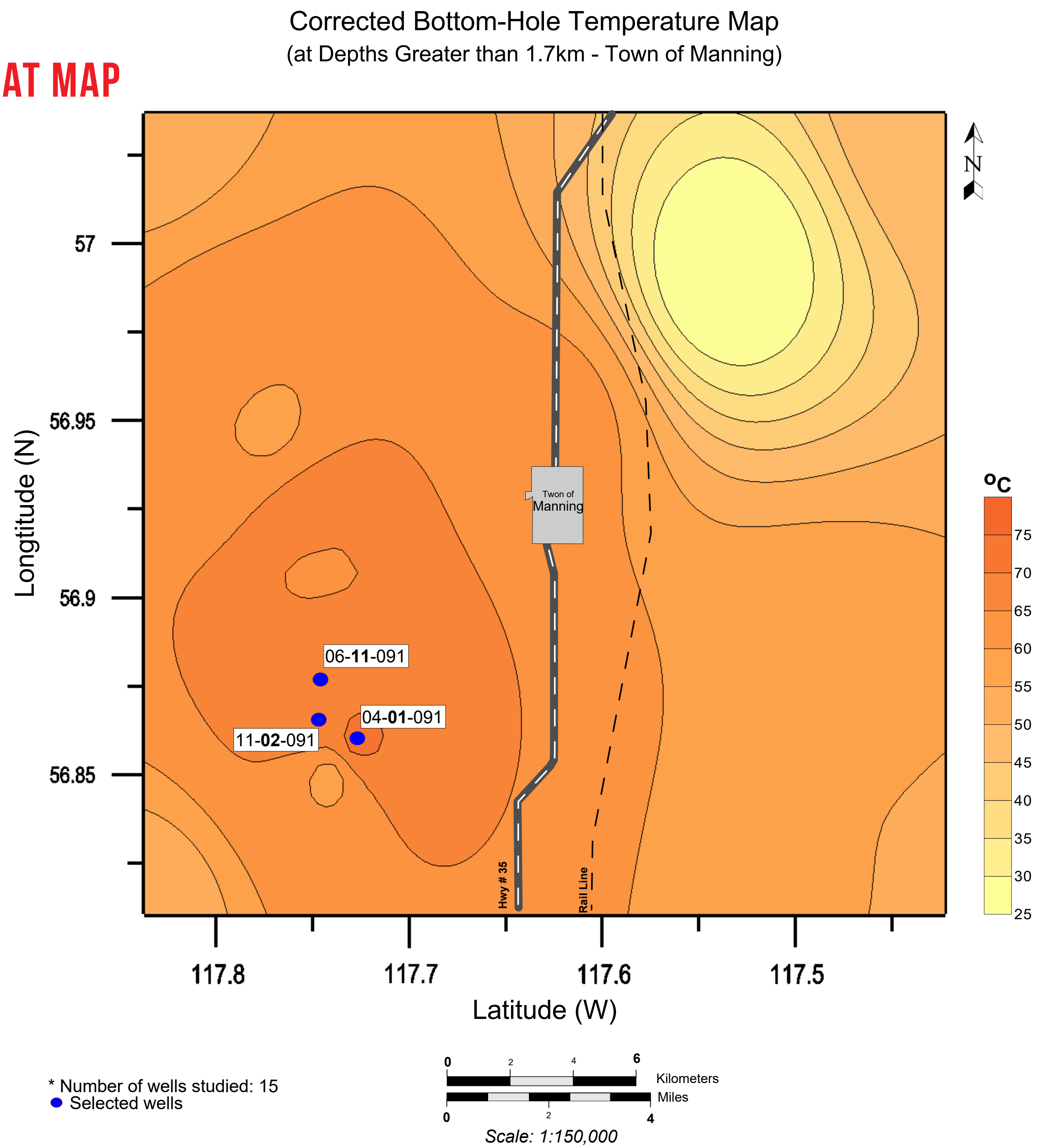
The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

RESEARCH RESULTS: MANNING

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

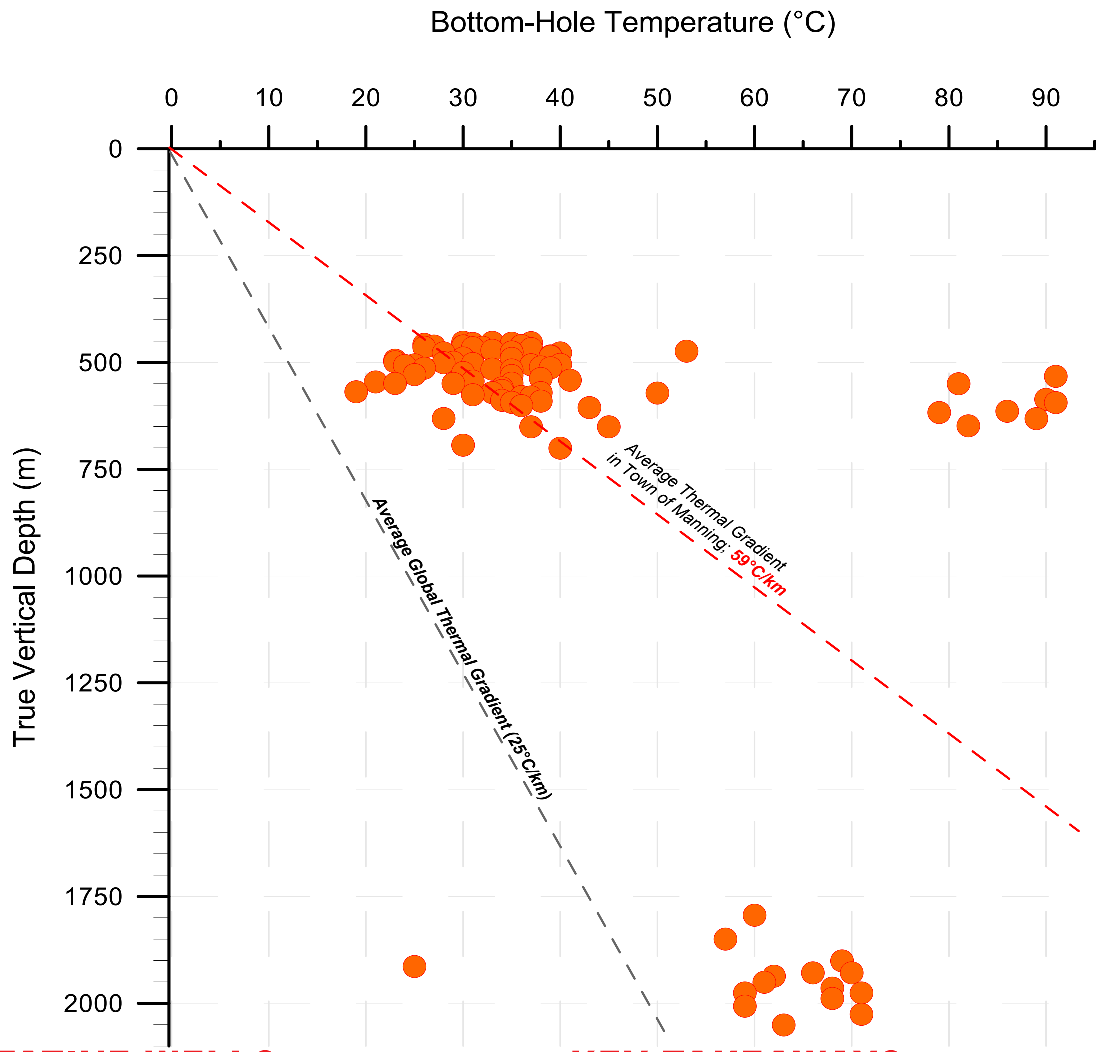
HEAT MAP



RESEARCH RESULTS: MANNING

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 3 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Gilwood Member (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/11-02-091-24W5/00	1983.3	-65	68	70	Surge Enrg Inc
102/04-01-091-24W5/00	1970.9	-70.6	71	75	Mancal Enrg Inc
100/06-11-091-24W5/00	1959	-65.2	68	70	Surge Enrg Inc

KEY TAKEAWAYS

- The productive geothermal formations underlying the study area are the **Gilwood** member and the **Granite Wash** formation.
- The indicated geothermal gradient in your area is **59°C/km** and is likely influenced by the shallowness of the region's wells
- Based on currently available data, there is potential for **geo-exchange** activities in your region and possible **direct-use** at greater depths

RECOMMENDATION & NOTES

Our study of the geothermal potential surrounding Manning has uncovered a number of factors detrimental to large-scale geothermal development. First, the identified productive formations underlying the town are relatively thin and cool. This suggests that they may not be able to support sustained direct-use activities. As well, the relative shallowness of the wells drilled in the study area indicates that the geothermal gradient may be influenced by the thermal conductivity of shallow rock layers, potentially anomalous readings, improper measurement techniques, or data entry errors and has led to an overestimation of the temperature potential in the region. It is recommended that the town investigate potentially higher temperatures at a depth greater than 2000m as well as the opportunity to build geo-exchange systems to take advantage of the relatively stable temperature below the frostline.

September 25, 2018

Geothermal Analysis

Peace River

Study by Terrapin Geothermics

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

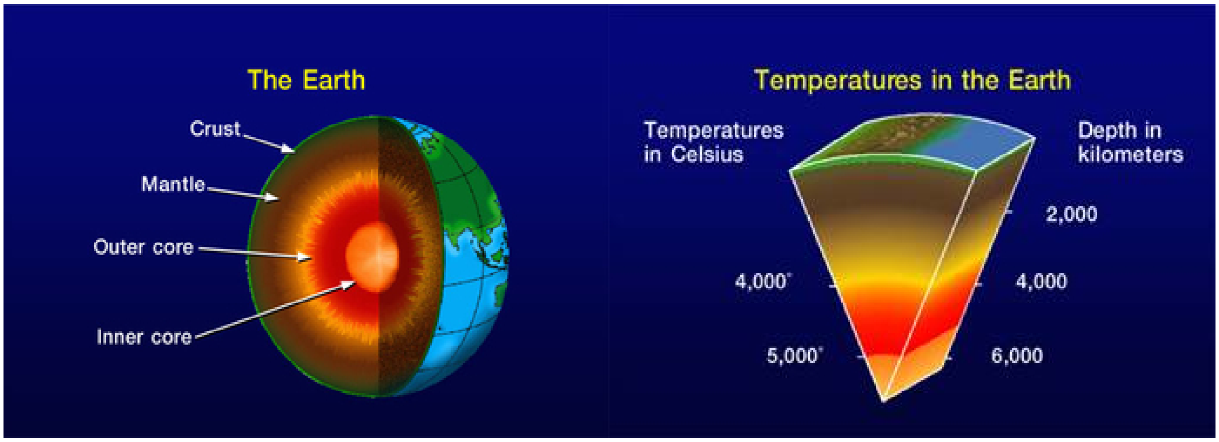
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

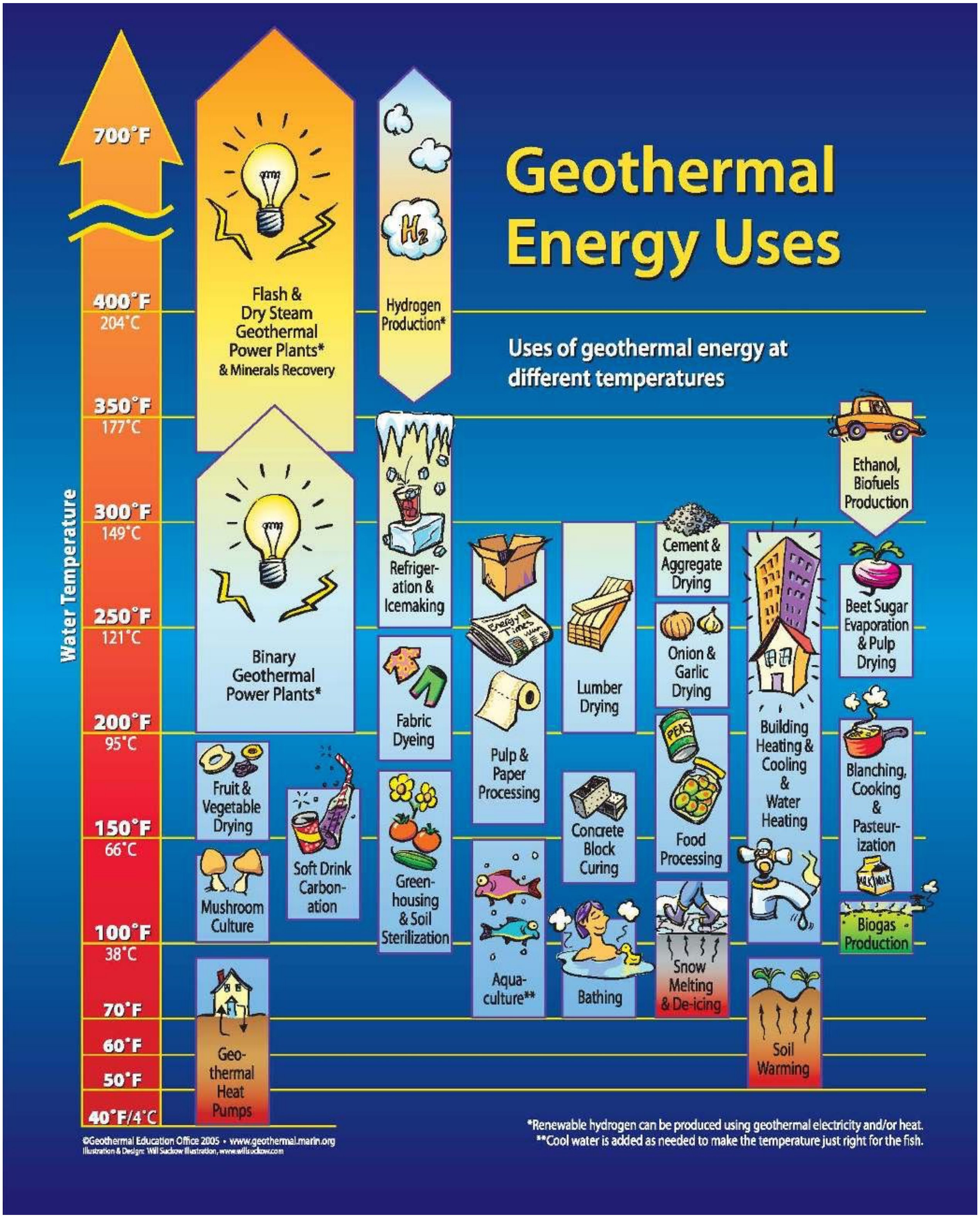
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180^{o}C and above), medium (100-180^{o}C), and low (80-100^{o}C) temperature resources with fluids under 80^{o}C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235^{o}C or above); flash plants (turning geothermal fluids of at least 150^{o}C into steam to drive a turbine); and binary power plants (using hot waters above 80^{o}C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180^{o}C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

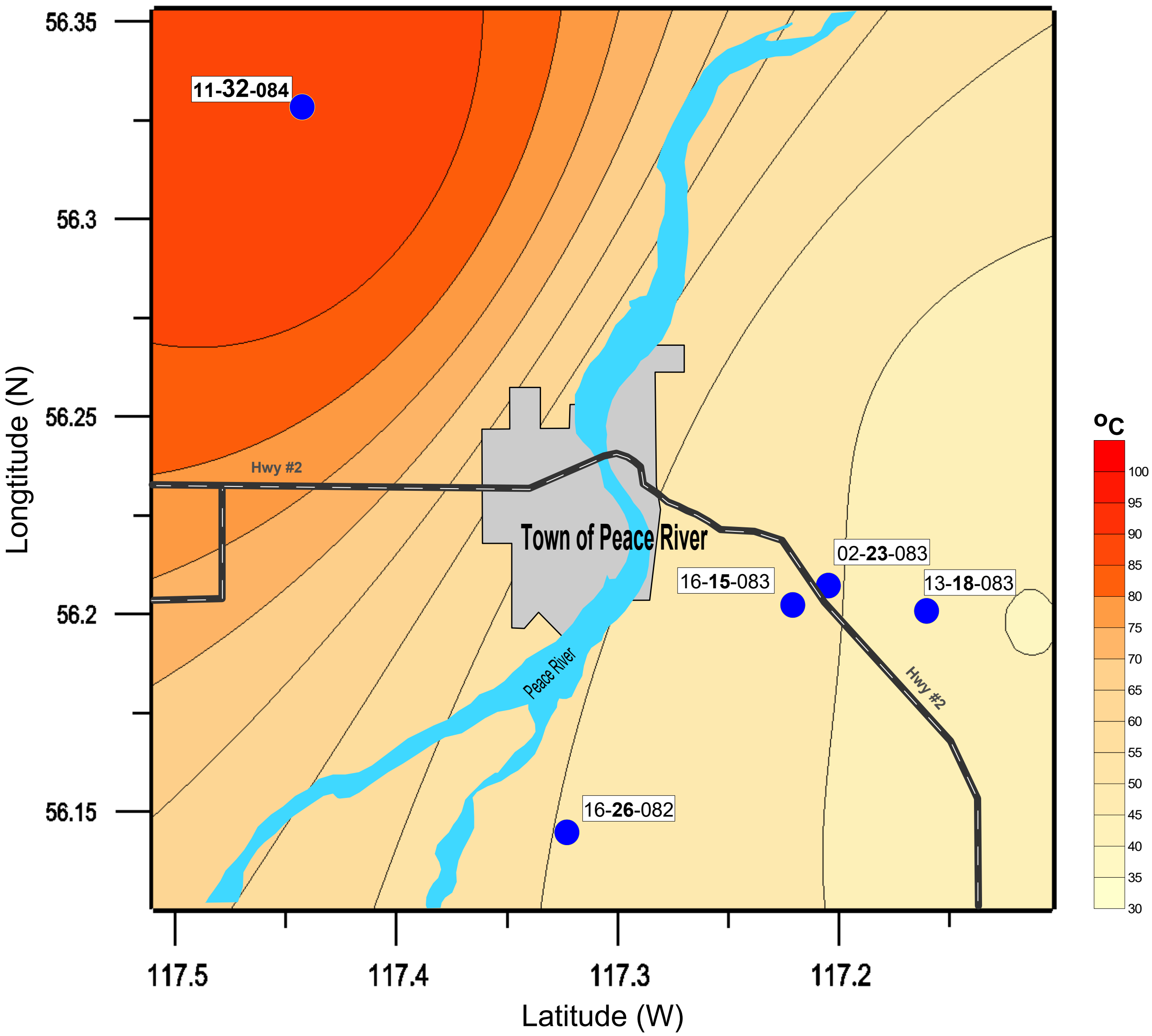
RESEARCH RESULTS: PEACE RIVER

CONTEXT

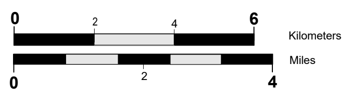
Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

HEAT MAP

Corrected Bottom-Hole Temperature Map
(at Depths Greater than 1km - Town of Peace River)

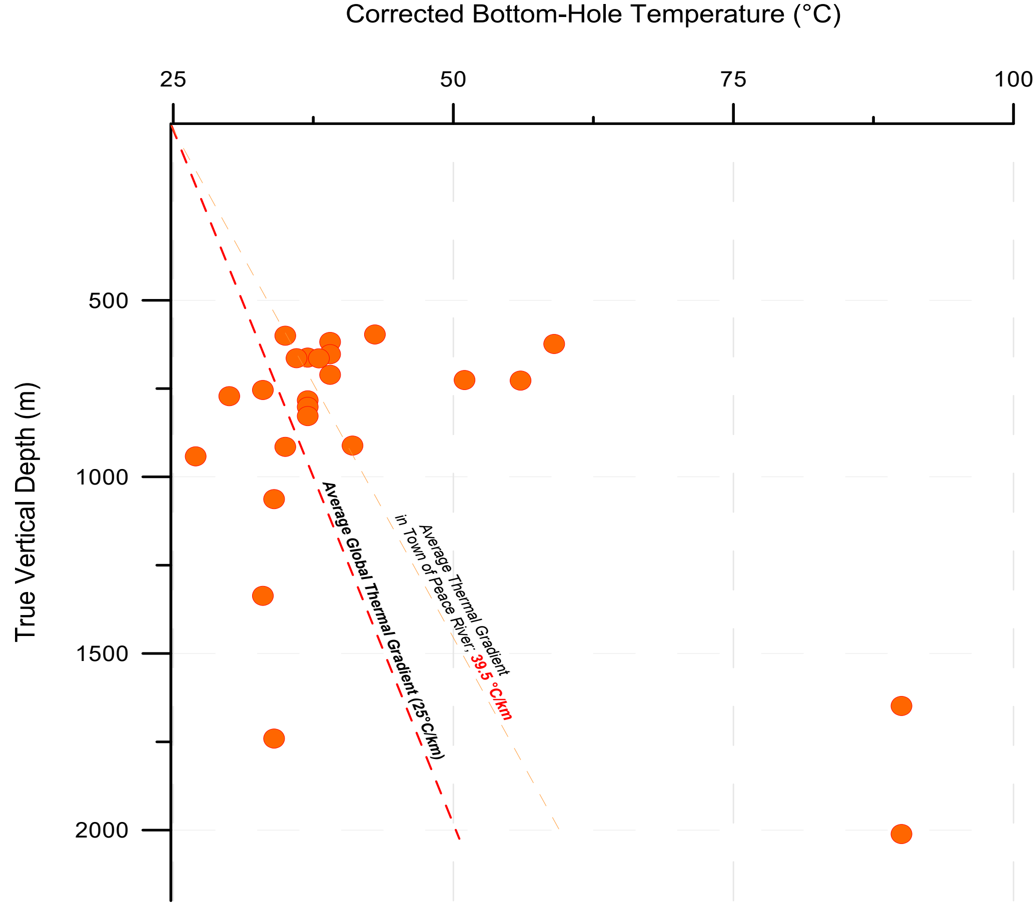


* Number of wells studied: 193
● Selected wells



Scale: 1:150,000

RESEARCH RESULTS: PEACE RIVER



TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.

TOP 5 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Leduc (m)	Corrected Bottom-Hole Temperature (°C)	Expected Temperature at Leduc Formation (°C)	Current Operator
100/02-23-083-21W5/00	2010.5	-217	56	97	Long Run Expl Ltd
100/16-26-082-22W5/00	1740.2	53.3	59	102	Cenovus Enrg Inc
100/13-18-083-20W5/00	1647.9	145.6	36	61	Paramount Rsrcs Ltd
100/16-15-083-21W5/00	1336.1	457.4	51	88	Long Run Expl Ltd
100/11-32-084-22W5/00	1062.3	731.2	90	<120	ExxonMobil Cda Rsrcs Co

KEY TAKEAWAYS

- The ideal formation for geothermal production in your area is the **Leduc Formation**
- The Pre-Cambrian basement and ideal formations are shallow with the Leduc Formation top at **1793.5m** and the basement at **2km** depth. This is 1-2km shallower than the majority of Alberta.
- The geothermal gradient in Peace River is **39.5°C/km**. This is **58%** better than the global average.
- Strong potential for **direct heat use** applications exists in the northwest of the study area.

RECOMMENDATION & NOTES

Our initial study of Peace River has uncovered a number of geological phenomenon that are beneficial to geothermal development. The ideal geothermal fluid-bearing formations are shallow, allowing for easier access, and have a generous thickness of 206.5m. This thickness should be able to store large amounts of fluid and heat. It is strongly recommended that Peace River pursue direct-use opportunities in the northwest of the study area. Specific research should include a look at the broader region surrounding Peace River for additional geological anomalies; investigating the local porosity and permeability within the identified target formation; and the creation of detailed energy potential models to assess the magnitude of this opportunity.

September 25, 2018

Geothermal Analysis

Sexsmith

Study by Terrapin Geothermics

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above 0^oC.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

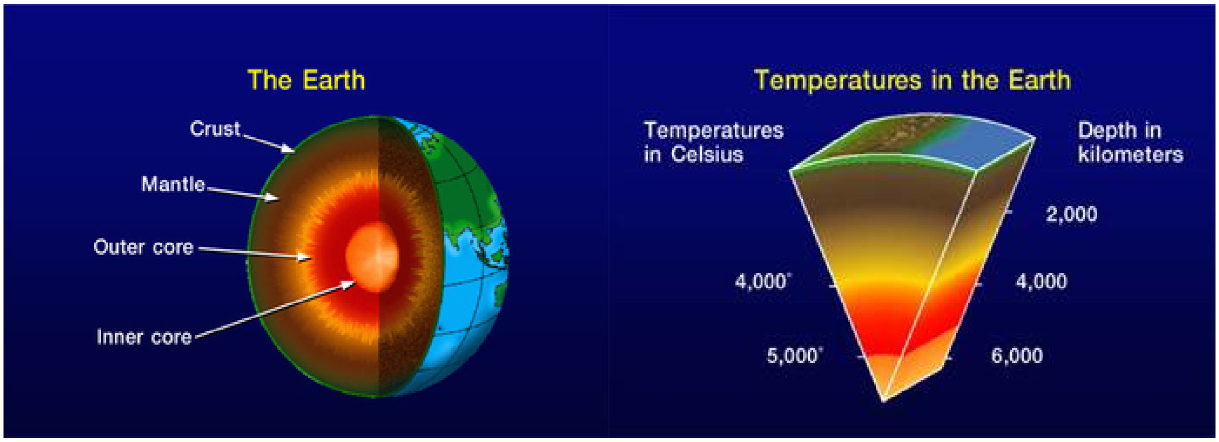
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

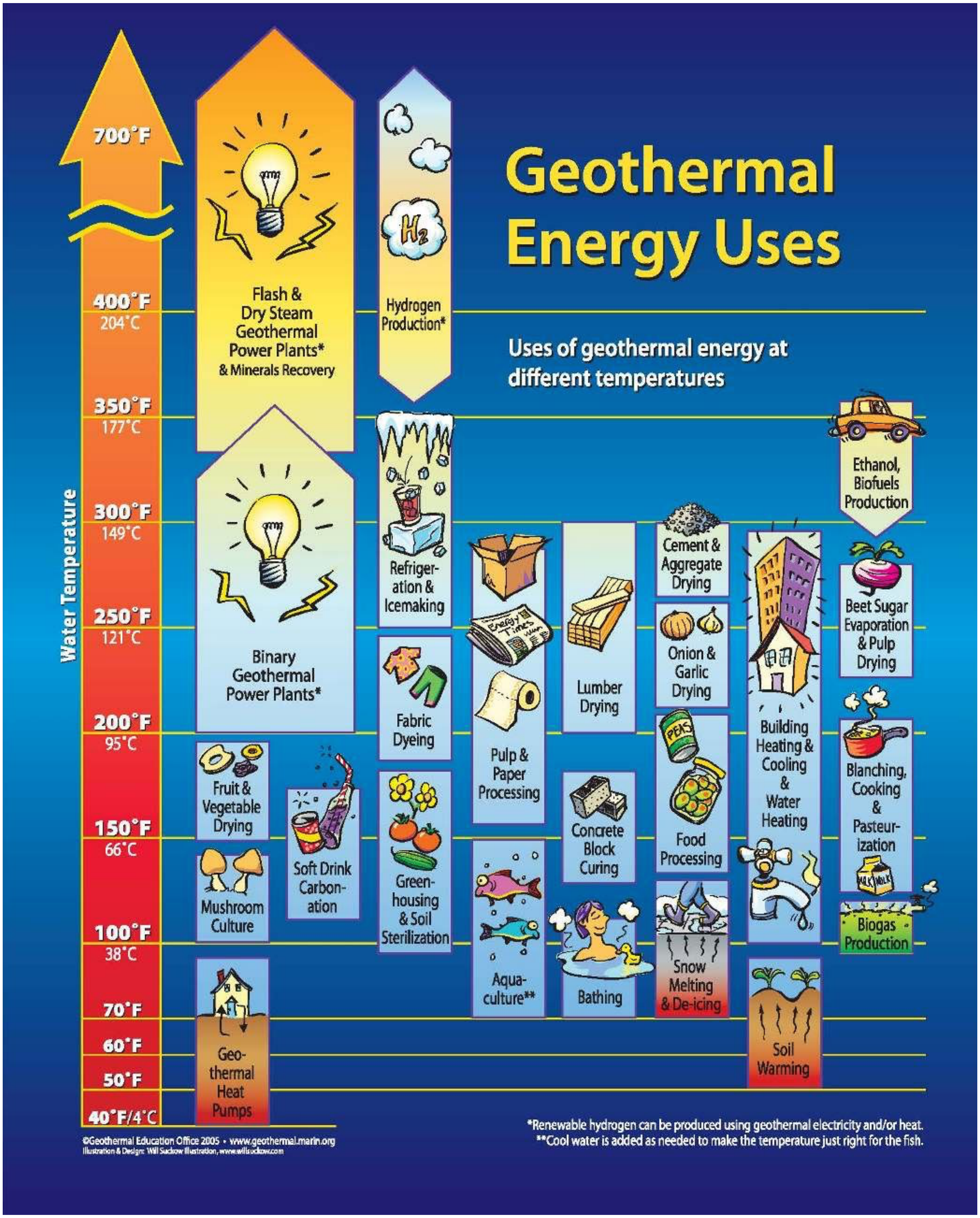
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180ºC and above), medium (100-180ºC), and low (80-100ºC) temperature resources with fluids under 80ºC being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235ºC or above); flash plants (turning geothermal fluids of at least 150ºC into steam to drive a turbine); and binary power plants (using hot waters above 80ºC to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180ºC.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

---

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

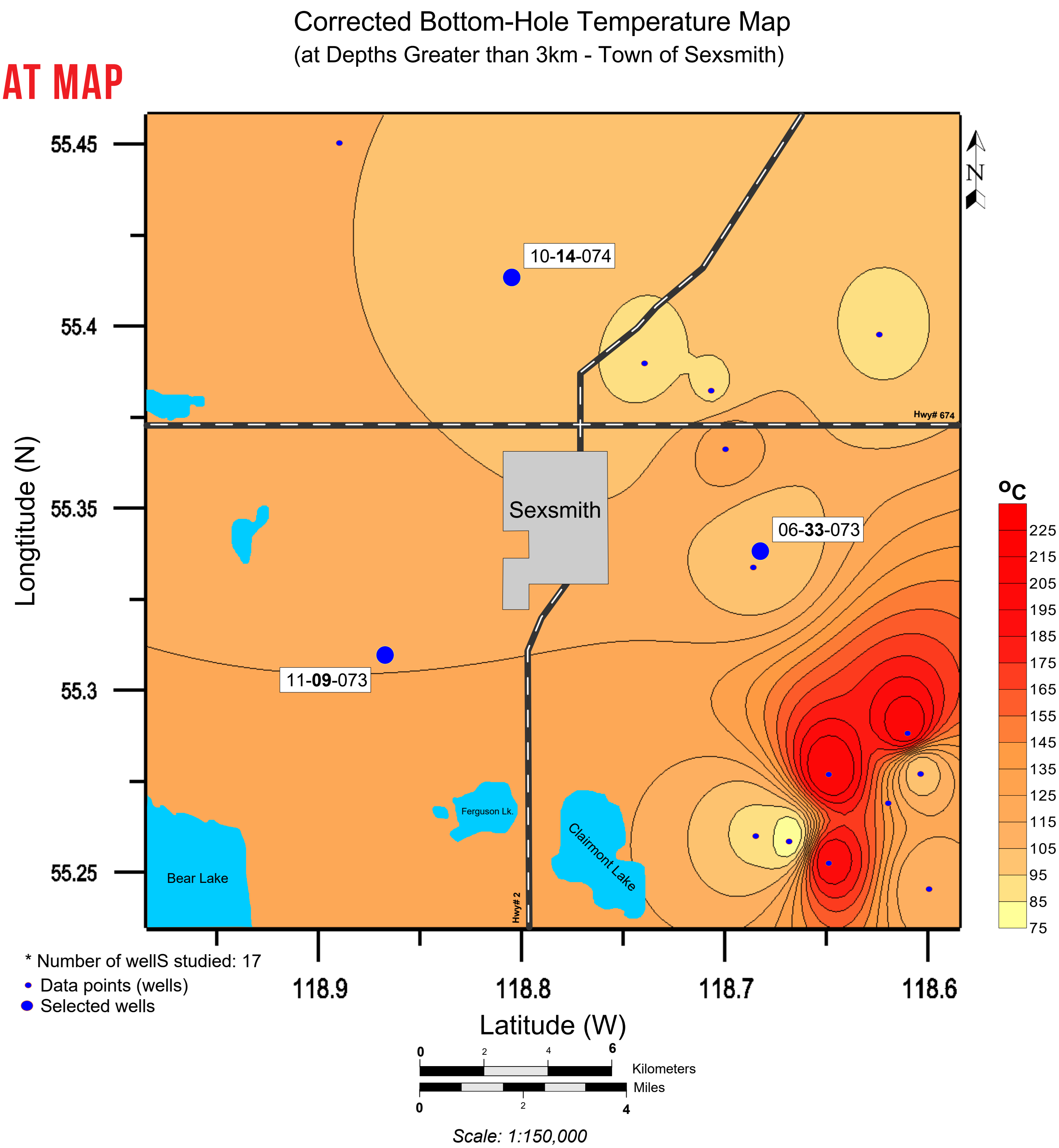
The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

RESEARCH RESULTS: SEXSMITH

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

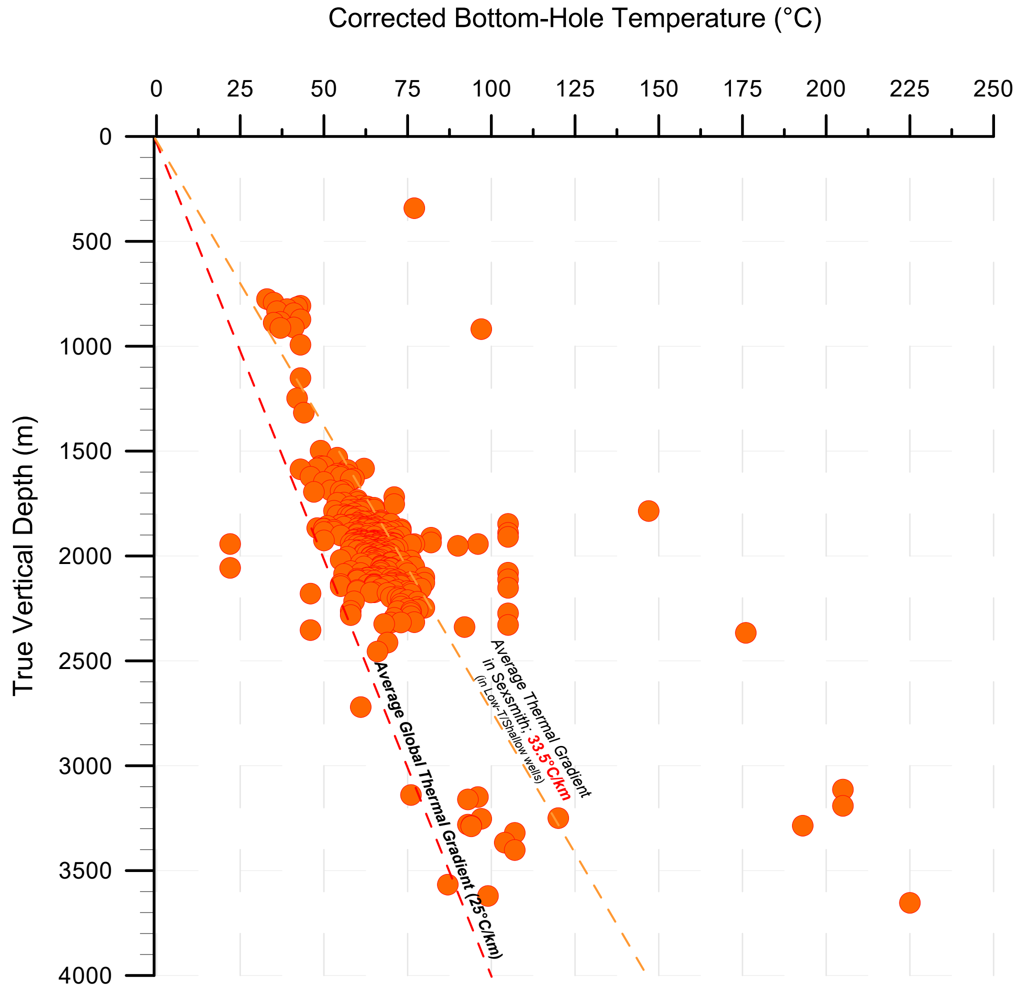
HEAT MAP



RESEARCH RESULTS: SEXSMITH

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 3 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Granite Wash F. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/10-14-074-06W6/00	3365.3	155.5	104	120	Repsol O&G Cda Inc
100/06-32-074-06W6/00	3619.6	-118.8	99	120	Cdn Nat Rsrcs Ltd
100/11-09-073-06W6/00	3652.4	-148.1	225	250	BP Cda Enrg Grp ULC

KEY TAKEAWAYS

- The productive geothermal formation in the study area is the **Granite Wash** formation.
- The average thermal gradient of the study area is **33.6ºC/km**. That is **34% higher** than the global average gradient.
- There are a number of deep wells drilled in your region, some deeper than **3600m**.
- The temperature readings in the study area indicate strong potential for **direct use** applications.

RECOMMENDATION & NOTES

There are 5 data points restricted to the southeast of the study area that indicate temperatures of over 175ºC. Temperatures in this range could support power generation activities but we have removed these points from our initial analysis as they appear to be measurement or data entry errors. However, Terrapin does recommend that a study be undertaken to verify this assumption as the potential does exist for a localized geological anomaly in this area. Further investigations suggested for the rest of the study area are to map fluid flows within target formations surrounding Sexsmith, and the creation of detailed thermal energy potential models to provide a basis for understanding the heat-use opportunities for any future development activity.

September 25, 2018

Geothermal Analysis

Slave Lake

Study by Terrapin Geothermics

For further information,
contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

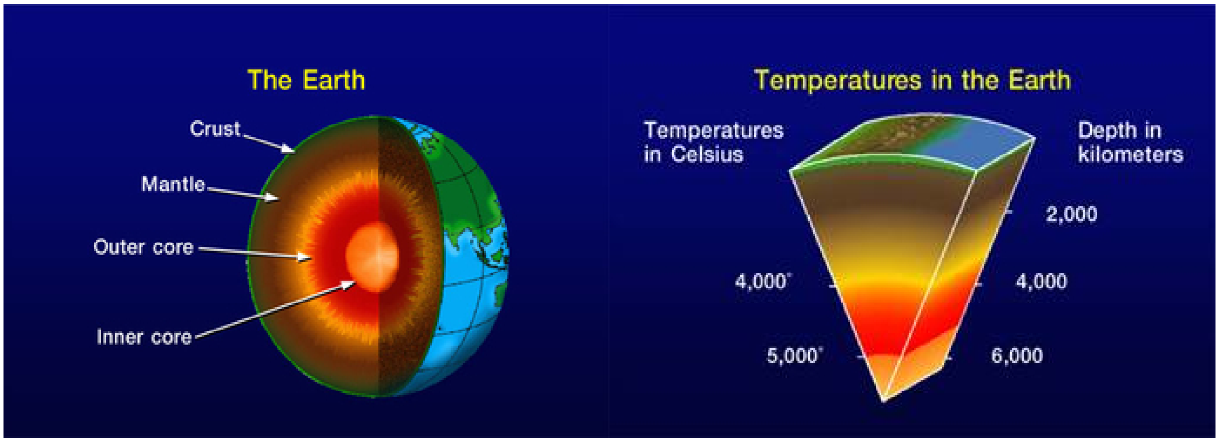
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

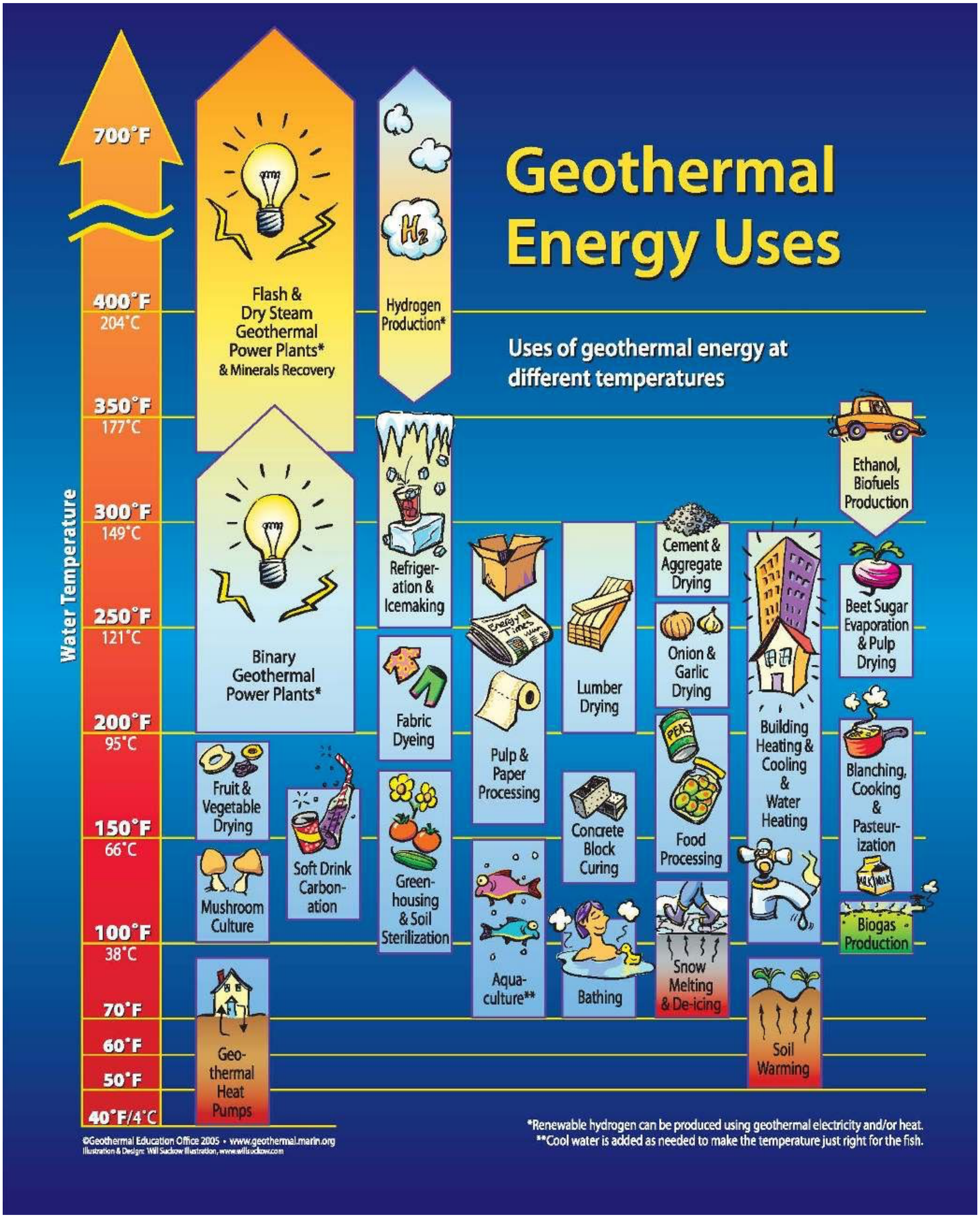
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160^{o}C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180^{o}C and above), medium (100-180^{o}C), and low (80-100^{o}C) temperature resources with fluids under 80^{o}C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235^{o}C or above); flash plants (turning geothermal fluids of at least 150^{o}C into steam to drive a turbine); and binary power plants (using hot waters above 80^{o}C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180^{o}C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

terrapin

RESEARCH RESULTS: SLAVE LAKE

CONTEXT

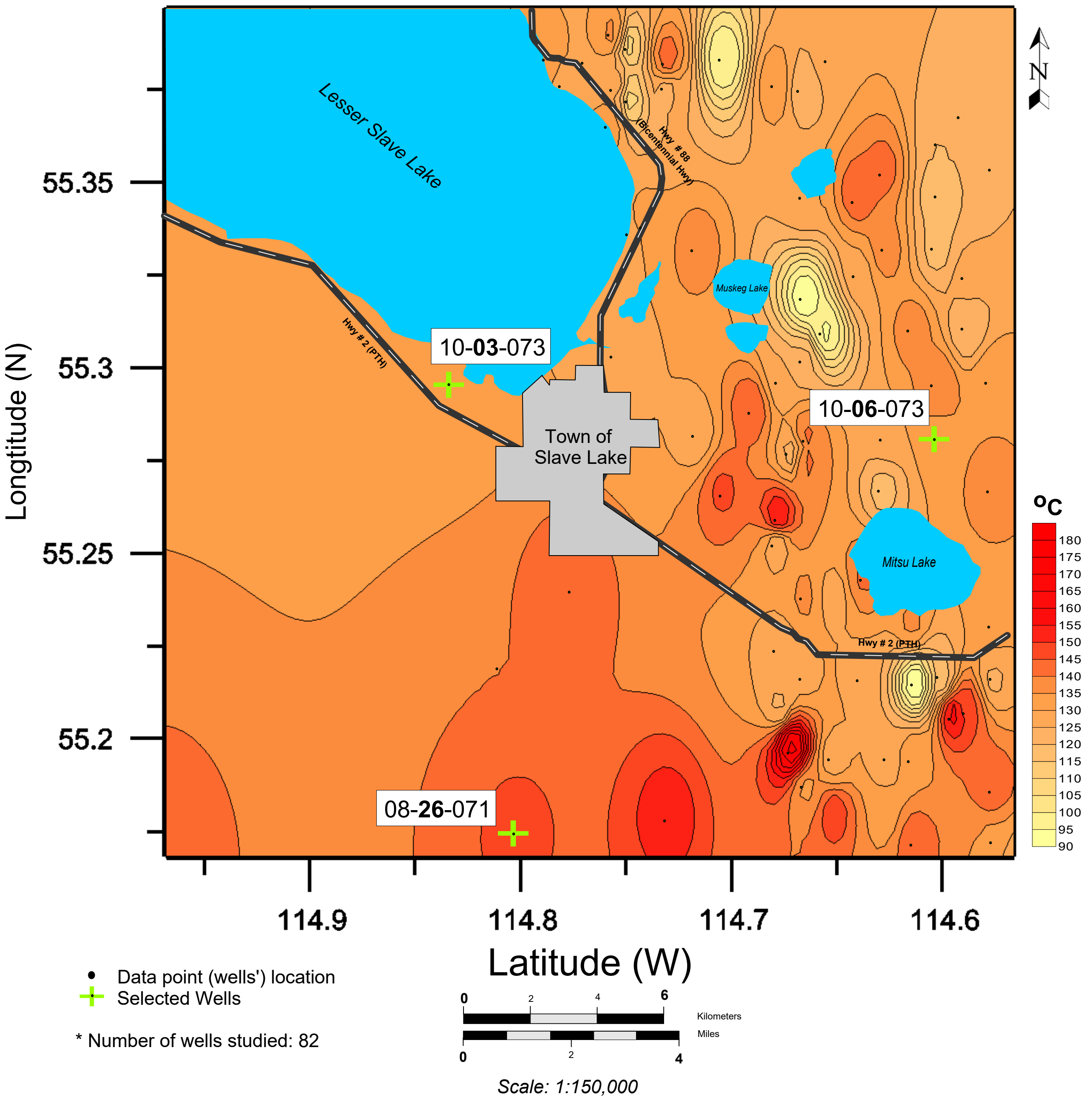
Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

HEAT MAP

Corrected Bottom-Hole Temperature Map

Moderate-Temperature Wells/Formation

(at Depths Greater than 1.6km - Town of Slave Lake)



RESEARCH RESULTS: SLAVE LAKE

terrapin

CONTEXT

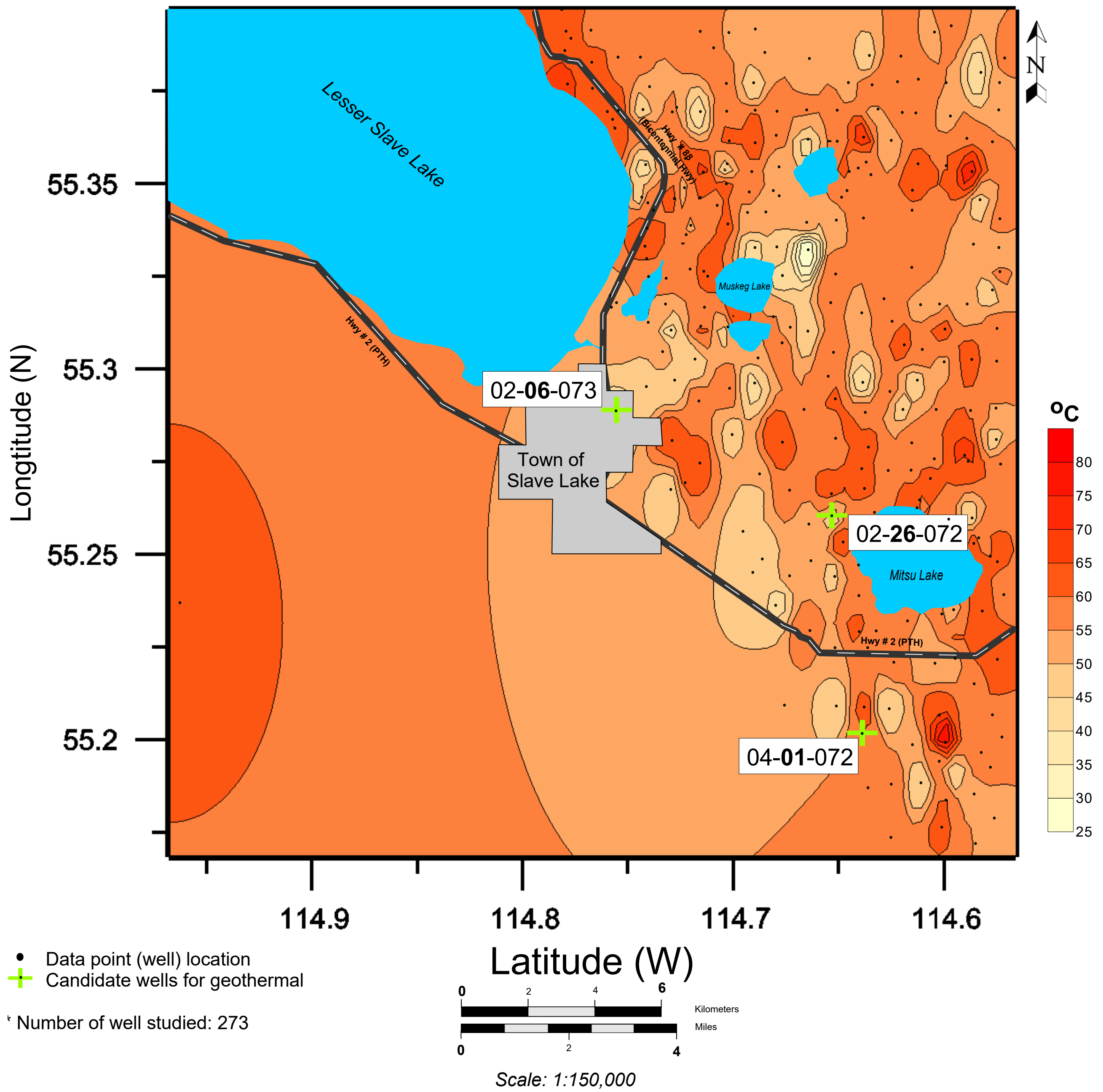
Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

HEAT MAP

Corrected Bottom-Hole Temperature Map

Low-Temperature Wells/Formation

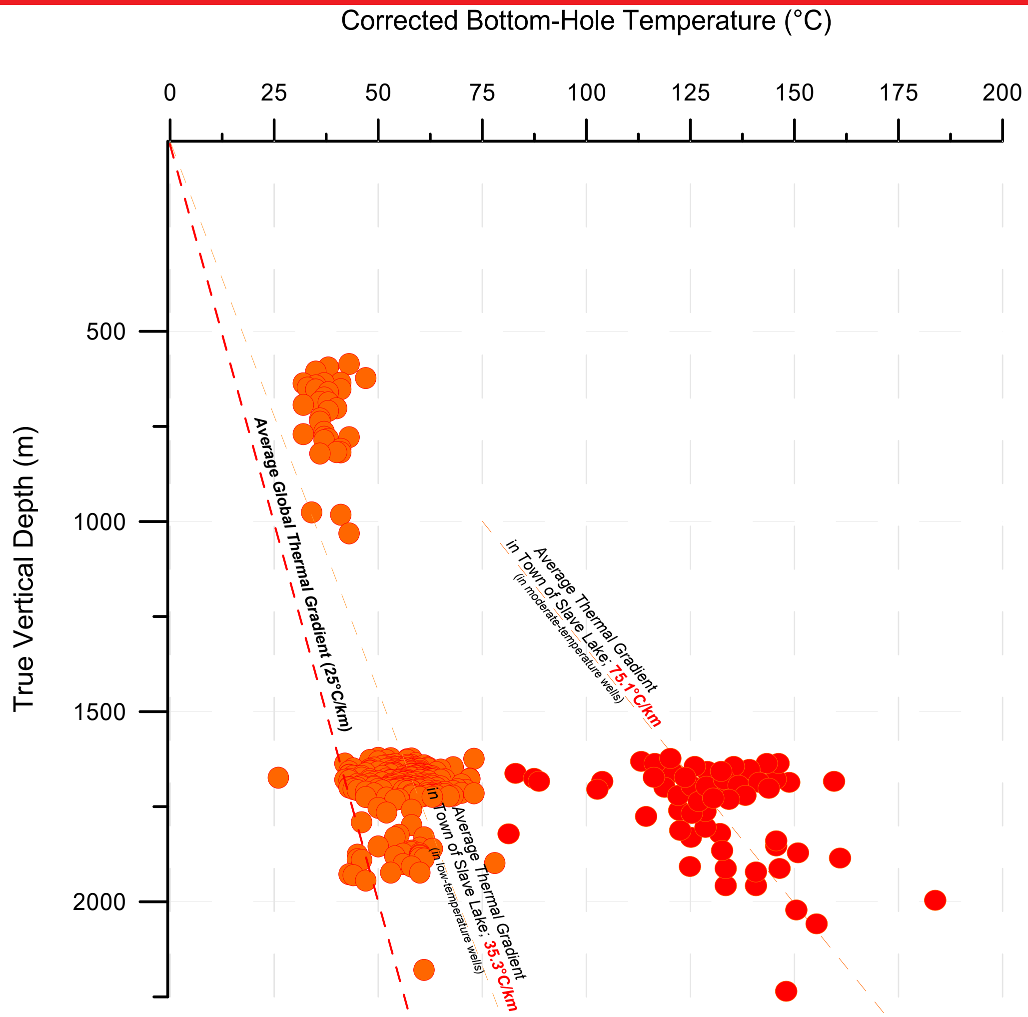
(at Depths Greater than 1.6km - Town of Slave Lake)



RESEARCH RESULTS: SLAVE LAKE

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 6 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Gilwood (m)	Corrected Bottom-Hole Temperature (°C)	Expected Temperature at the Base of Target Formations (°C)	Current Operator
100/10-06-073-04W5/00	1919.8	-319.5	140	150	Cardinal Enrg Ltd(2)
100/10-03-073-06W5/00	1955.9	-247.8	133	150	Imperial Oil Ltd
100/08-26-071-06W5/00	2252.1	-276.4	146	150	Shell Cda Ltd
100/04-01-072-05W5/00	1922.5	-214.4	60	90	Cardinal Enrg Ltd(2)
100/02-06-073-05W5/00	1929.3	-221.2	47	80	Imperial Oil Ltd
100/02-26-072-05W5/00	1943.4	-235.3	61	90	Cardinal Enrg Ltd(2)

KEY TAKEAWAYS

- The ideal formation for geothermal energy in your region is the **Gilwood formation**
- The blended temperature gradient in Slave Lake is **43.3°C.** This is **73%** better than Alberta's average with the moderate-high grouping over **200%** better than Alberta's average
- Strong potential for **power generation** exists
- In the **top 2%** of surveyed results across Alberta

RECOMMENDATION & NOTES

Our research work around Slave Lake identified two distinct data sets: a low-moderate grouping and a moderate-high temperature grouping. The moderate-high grouping is amongst the strongest geothermal potential that our geology team has discovered in Alberta outside the Rocky Mountains. It is very strongly recommended that Slave Lake pursue further research in this area. Specific studies should expand the scope to the surrounding areas, seek to validate this initial data, map fluid flows within target formations and create detailed energy potential models to assess the magnitude and viability of this seemingly large opportunity.

September 25, 2018

Geothermal Analysis

St. Paul

Study by Terrapin Geothermics

terrapin

For further information,
contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

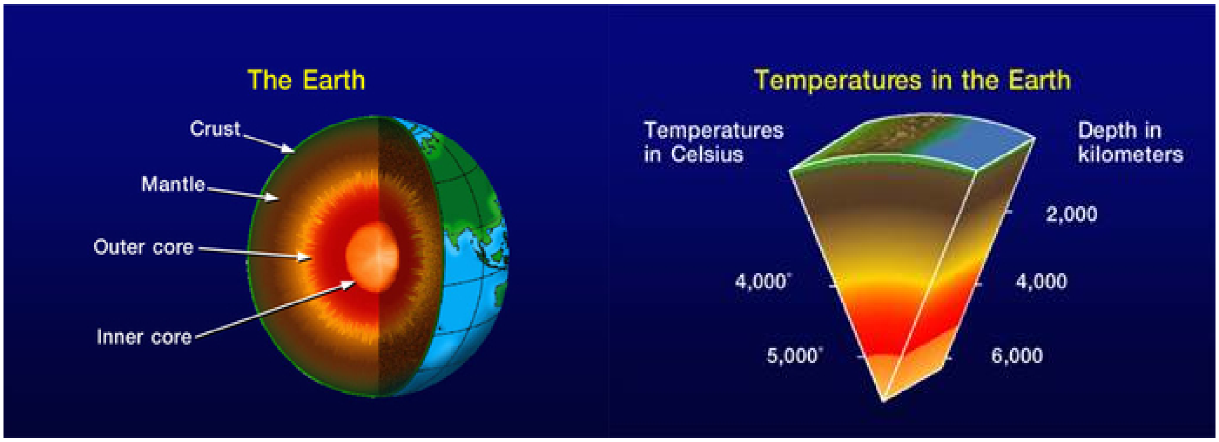
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

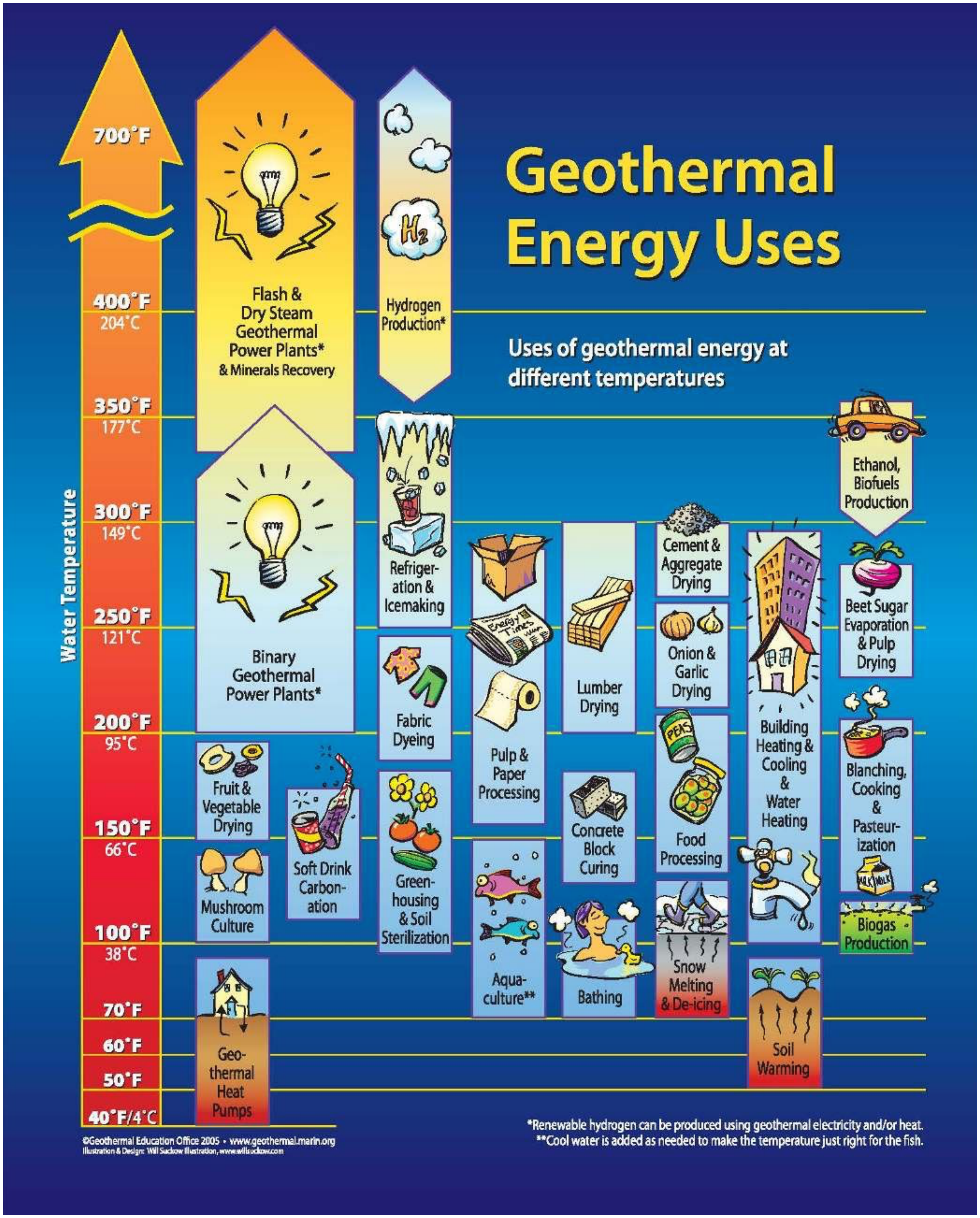
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180^{o}C and above), medium (100-180^{o}C), and low (80-100^{o}C) temperature resources with fluids under 80^{o}C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235^{o}C or above); flash plants (turning geothermal fluids of at least 150^{o}C into steam to drive a turbine); and binary power plants (using hot waters above 80^{o}C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180^{o}C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

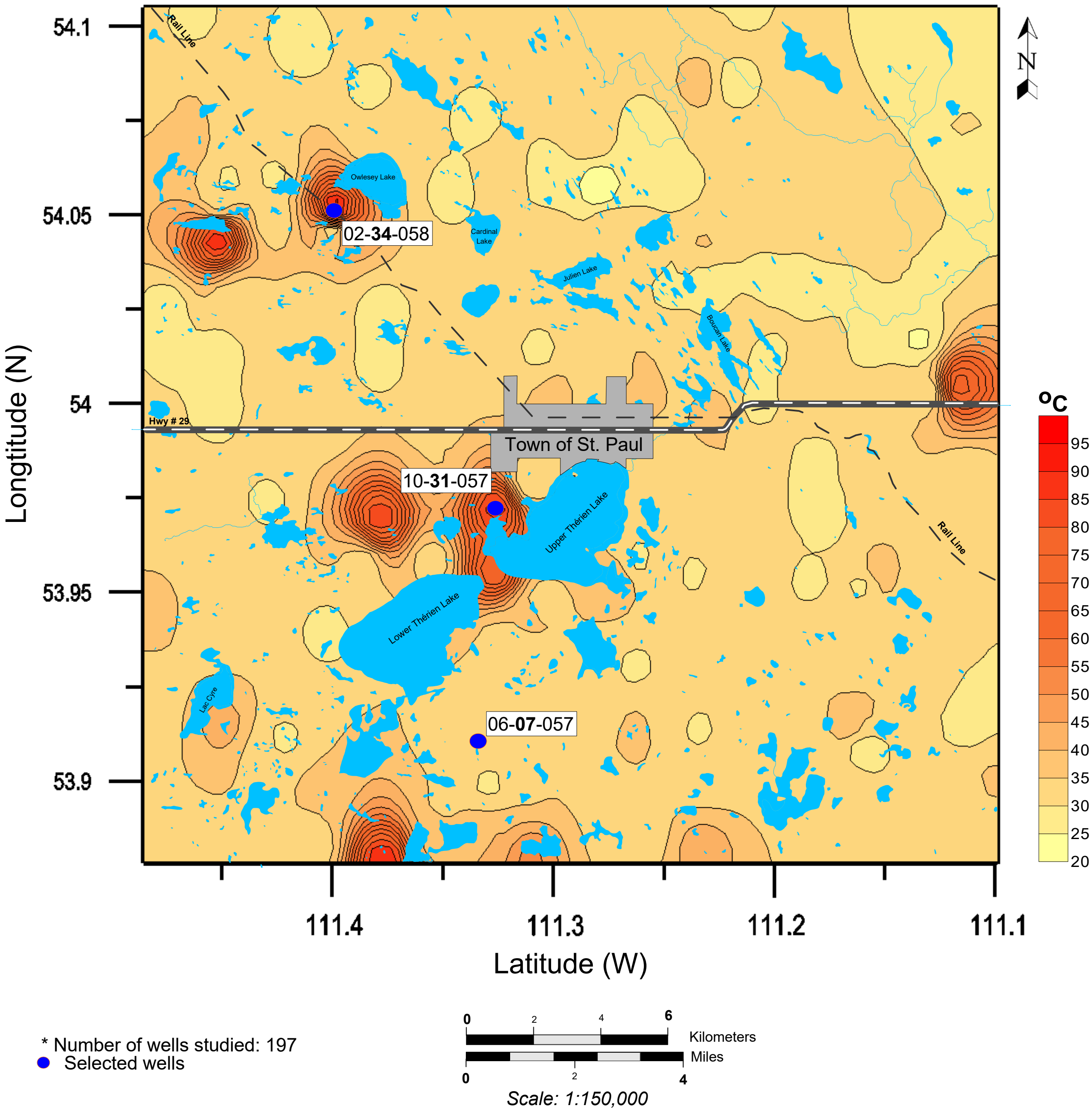
RESEARCH RESULTS: ST. PAUL

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

HEAT MAP

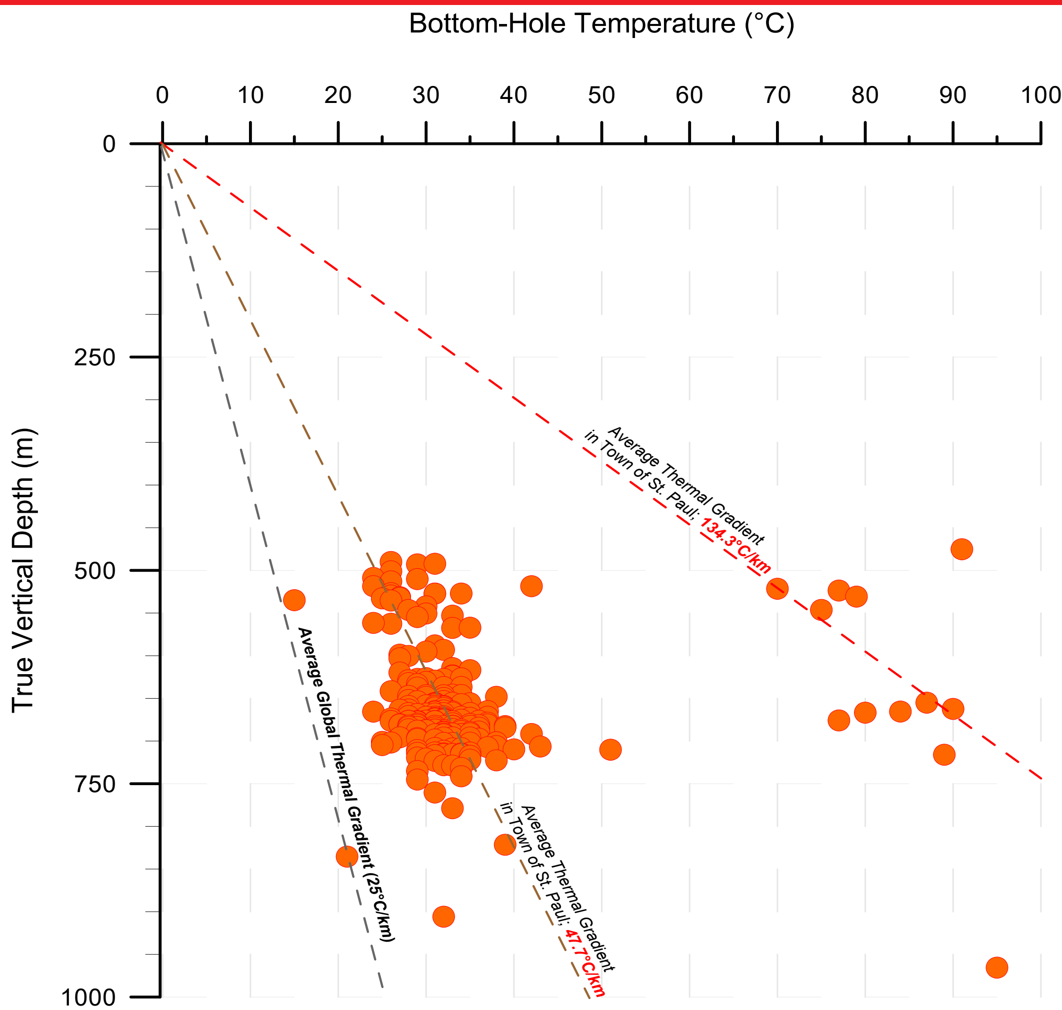
Corrected Bottom-Hole Temperature Map
(at Depths Greater than 0.6km - Town of St. Paul)



RESEARCH RESULTS: ST. PAUL

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 3 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Devonian Strata	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/10-31-057-09W4/00	658.4	-658.4	87	120	Cdn Nat Rsrcs Ltd
102/04-01-091-24W5/00	1970.9	-70.6	71	75	Westates Expl Co
100/06-11-091-24W5/00	1959	-65.2	68	70	Gulf Cda Ltd

KEY TAKEAWAYS

- There are **no identified geothermally productive formations** underlying the study area
- There are two temperature data sets in the study area. The low-moderate data set indicates a temperature gradient of **47.7ºC/km** and the moderate-high data set shows a gradient of **134.3ºC/km**.
- Based on currently available data, there is potential for **geo-exchange** activities in the study area

RECOMMENDATION & NOTES

Our study of the geothermal potential surrounding the town of St. Paul has uncovered a number of factors detrimental to large-scale geothermal development. First, though the Devonian-aged strata are quite thick (695m) there are no productive geothermal formations present. As well, the majority of wells in the study area are cool and quite shallow, drilled to depths less than 750m, meaning that temperature readings are likely to have been influenced by the thermal conductivity of shallow rock layers, potential anomalous temperature readings, improper measurement techniques, or data entry errors and have led to a severe overestimation of the temperature potential in the region. It is recommended that the town investigate the opportunity to build geo-exchange systems to take advantage of the relatively stable temperature below the frostline.

September 25, 2018

Geothermal Analysis

Swan Hills

Study by Terrapin Geothermics

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

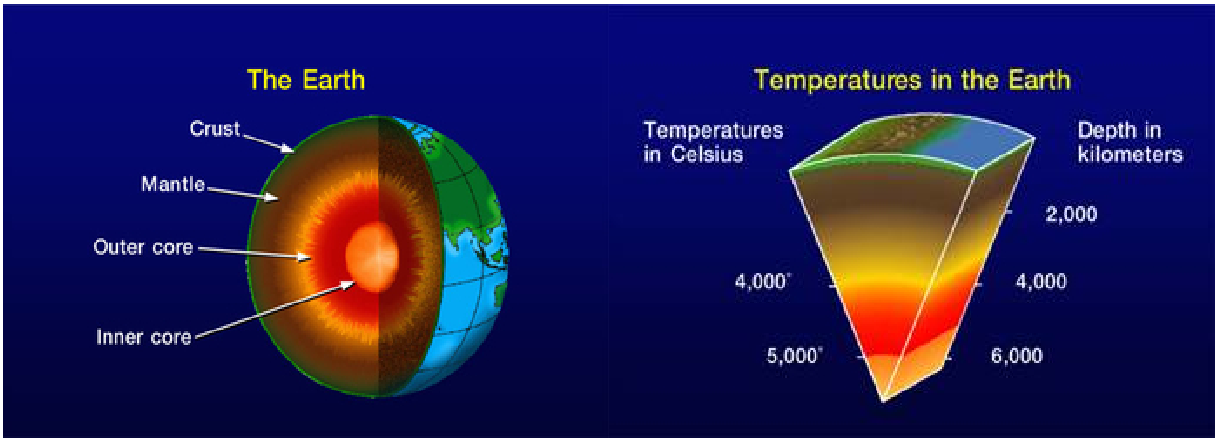
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

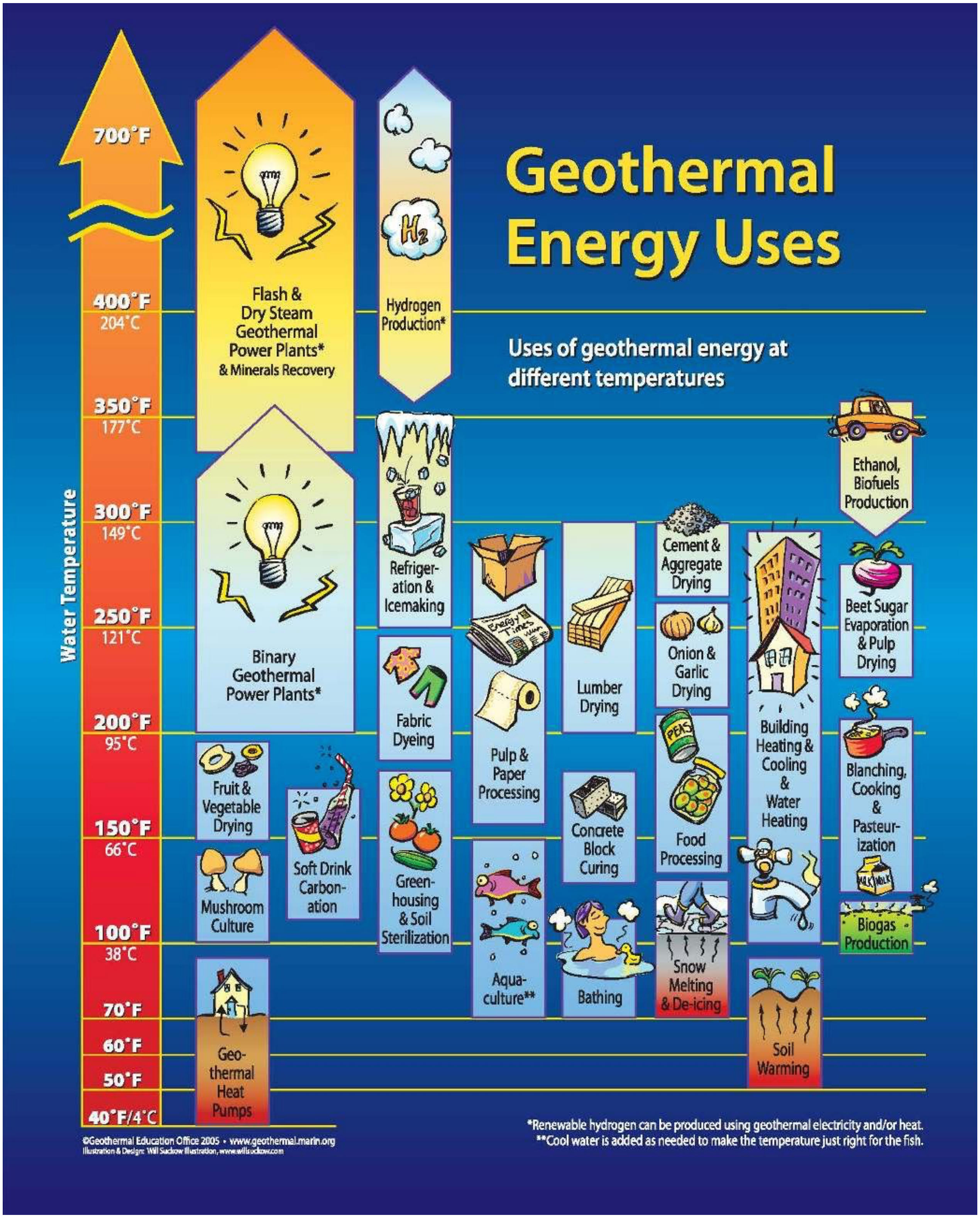
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160ºC and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180^{o}C and above), medium (100-180^{o}C), and low (80-100^{o}C) temperature resources with fluids under 80^{o}C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235^{o}C or above); flash plants (turning geothermal fluids of at least 150^{o}C into steam to drive a turbine); and binary power plants (using hot waters above 80^{o}C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180^{o}C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

---

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

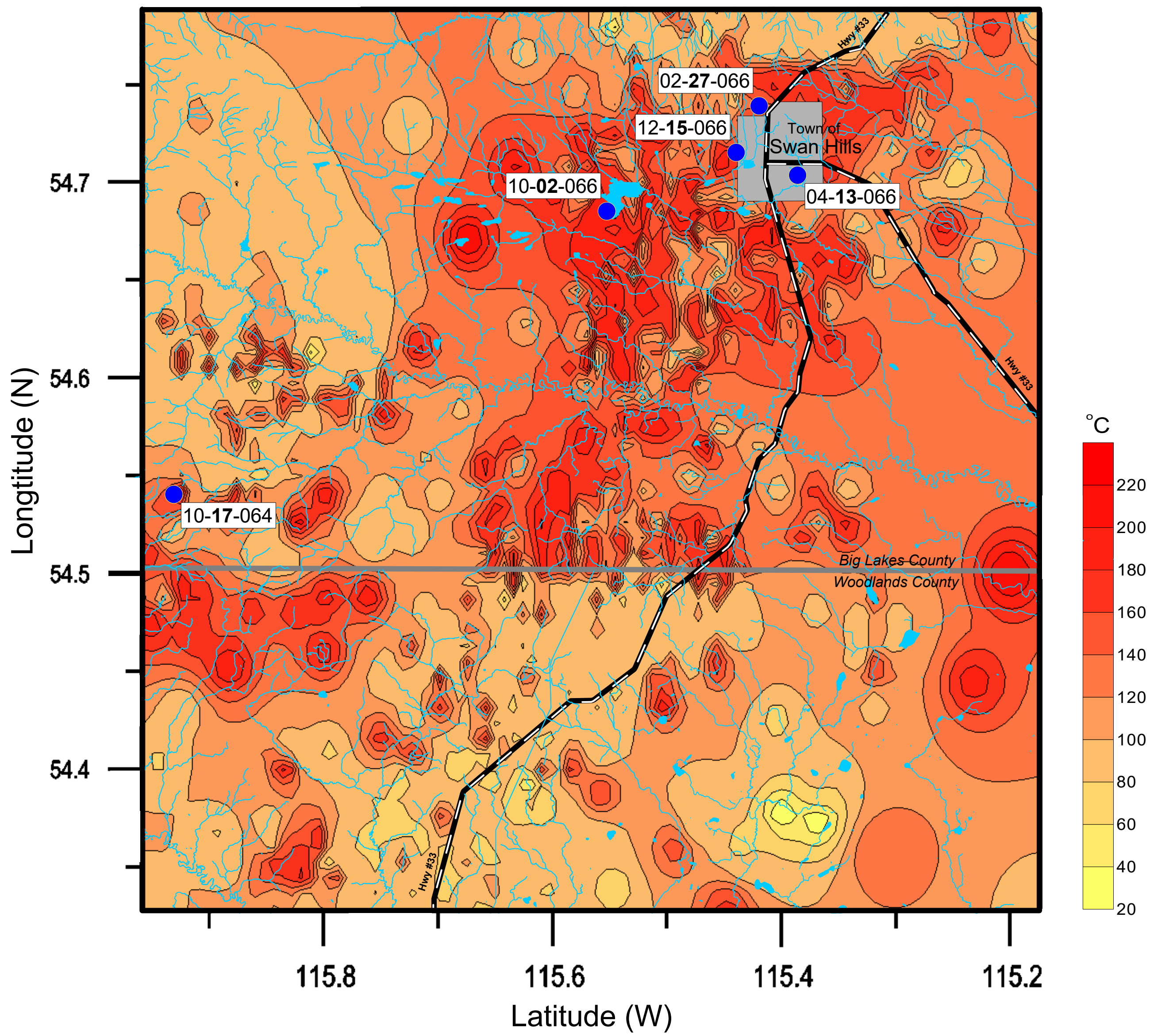
RESEARCH RESULTS: SWAN HILLS

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

HEAT MAP

Corrected Bottom-Hole Temperature Map
(at Depths Greater than 2.5km - Town of Swan Hills)



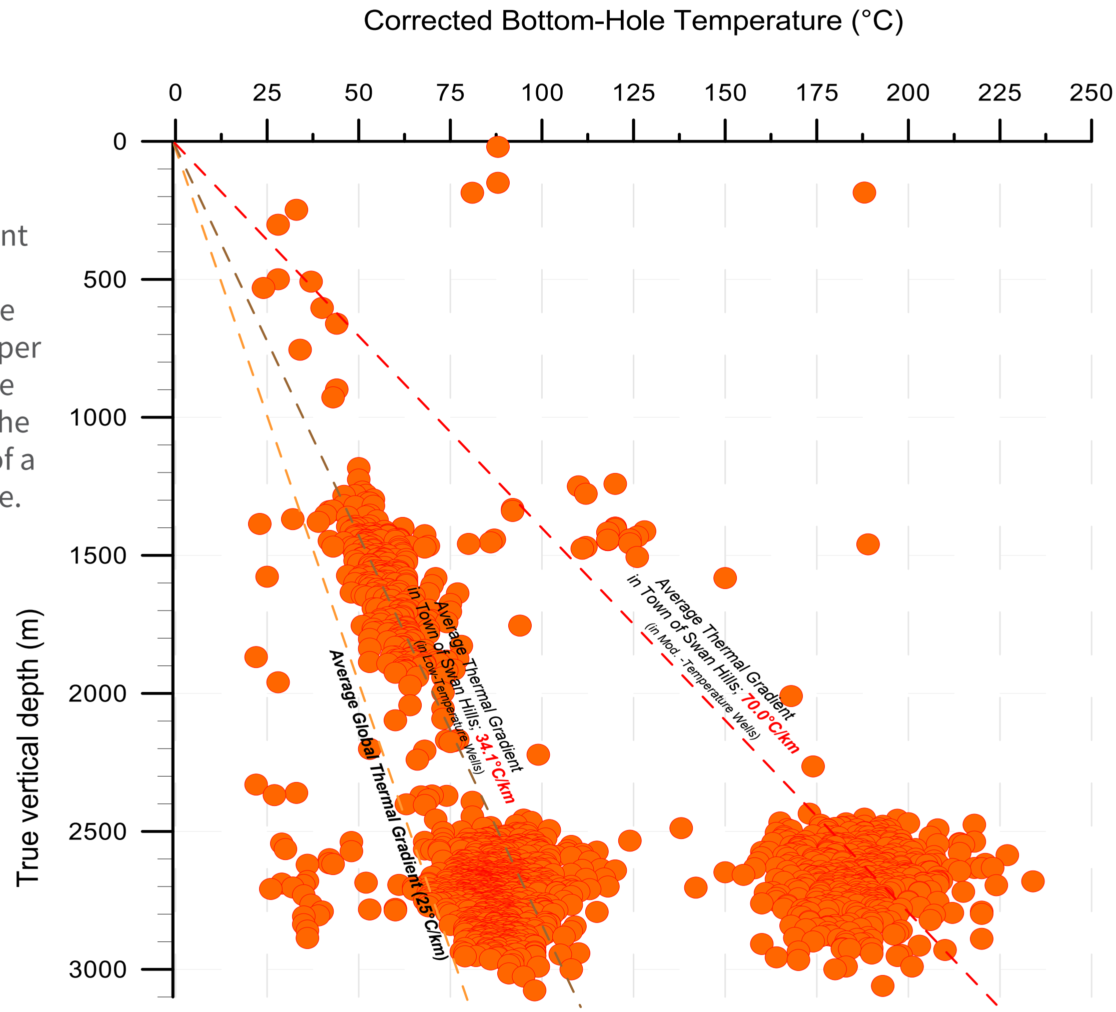
* Number of wells studied: 1490
● Selected wells

0 5 10 15 Kilometers
0 5 10 Miles
Scale: 1:250,000

RESEARCH RESULTS: SWAN HILLS

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 5 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Swan Hills F. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/12-15-066-10W5/00	2638	-56.1	187	190	Cdn Nat Rsrcs Ltd
100/10-02-066-11W5/00	2679.8	-103.1	234	240	Razor Enrg Corp(3)
100/02-27-066-10W5/00	2688	-37.5	176	190	Cdn Nat Rsrcs Ltd
100/04-13-066-10W5/00	2988.6	-403	201	210	Cdn Nat Rsrcs Ltd
100/10-17-064-13W5/00	3254.1	-338.6	213	215	Advantage O&G Ltd

KEY TAKEAWAYS

- The identified productive geothermal formations in your area are the **Swan Hills** formation and the **Gilwood** member.
- There are two sets of temperature measurements in your area: a low-moderate grouping with a gradient of **34.1ºC/km** and a moderate-high grouping with a gradient of **70ºC/km**.
- There is potential for **direct use and/or power generation** activities in the study area

RECOMMENDATION & NOTES

Our study of the town of Swan Hills has uncovered a large number of wells with the temperatures necessary to support geothermal activity, even within the town limits. These wells demonstrate some of the strongest geothermal potential our team has found in Alberta. Also, the recorded geothermal formations in the study area have a moderate thickness (230m) and may contain enough fluid to sustain geothermal activities. It is strongly recommended that the town of Swan Hills conduct a further, in-depth investigation of the geothermal potential within the area directly surrounding and including the town that seeks to validate this initial temperature and geological data, map fluid flows within target formations, and create detailed energy potential models to assess the magnitude and viability of this seemingly large opportunity.

September 25, 2018

Geothermal Analysis

Wabasca (South)

Study by Terrapin Geothermics

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above 0^{o}C.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

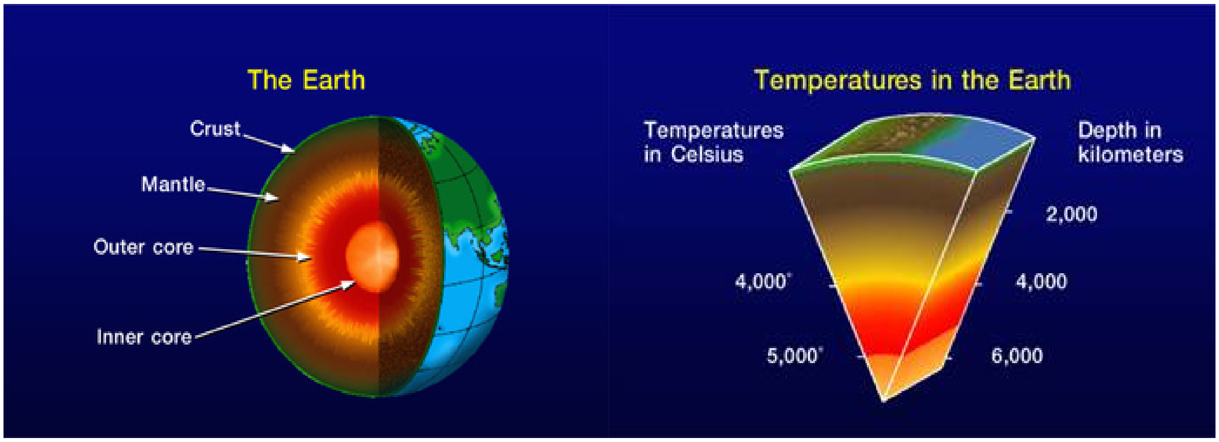
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

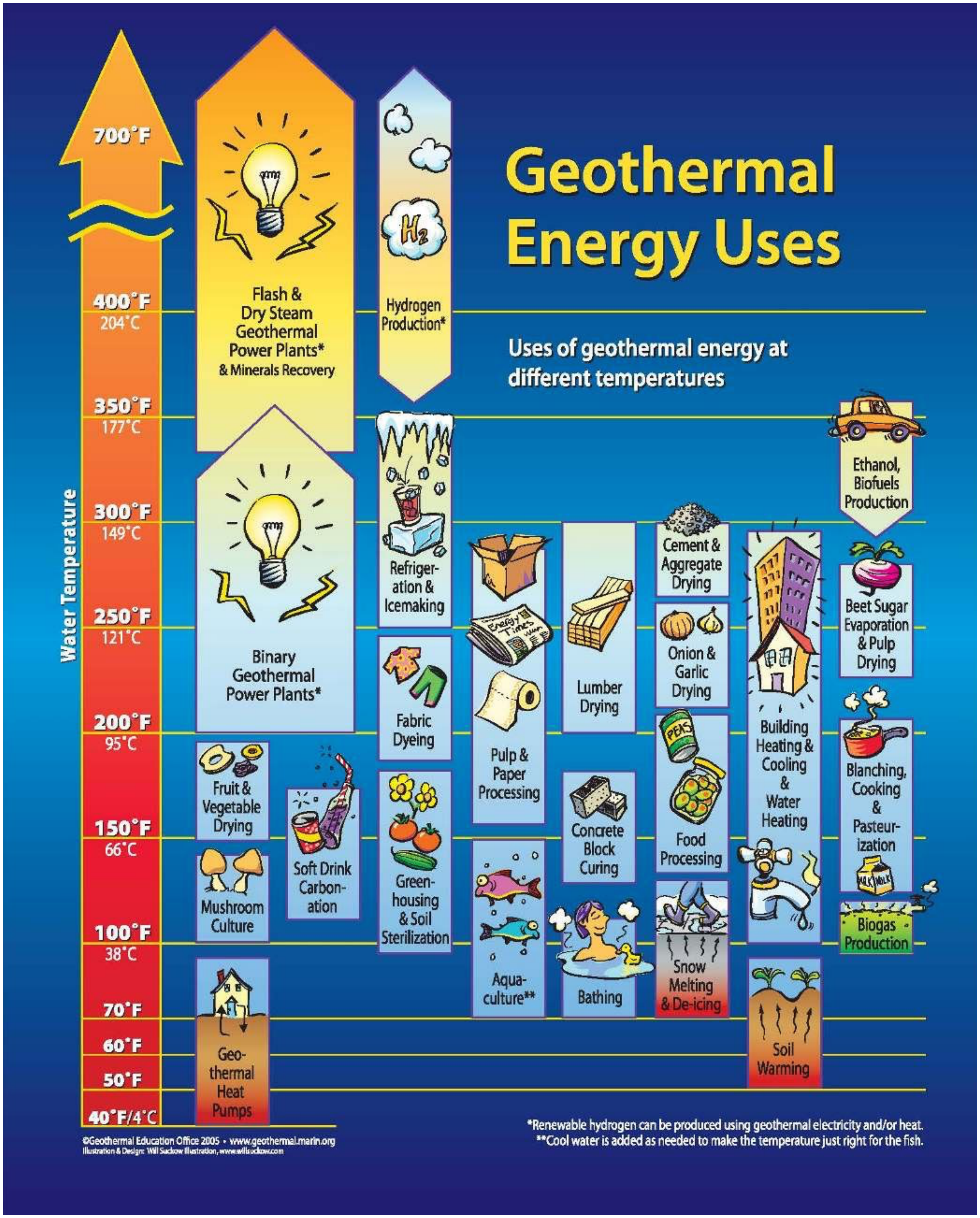
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

“Direct use” refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland’s homes and the district heating utility in Reykjavik serves approximately 60% of Iceland’s population.[1] A further example of direct use is the 5,000-acre Oserian Development Company’s flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160ºC and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., “85 Years of Successful District Heating in Reykjavík, Iceland”, *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180^{o}C and above), medium (100-180^{o}C), and low (80-100^{o}C) temperature resources with fluids under 80^{o}C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235^{o}C or above); flash plants (turning geothermal fluids of at least 150^{o}C into steam to drive a turbine); and binary power plants (using hot waters above 80^{o}C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180^{o}C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

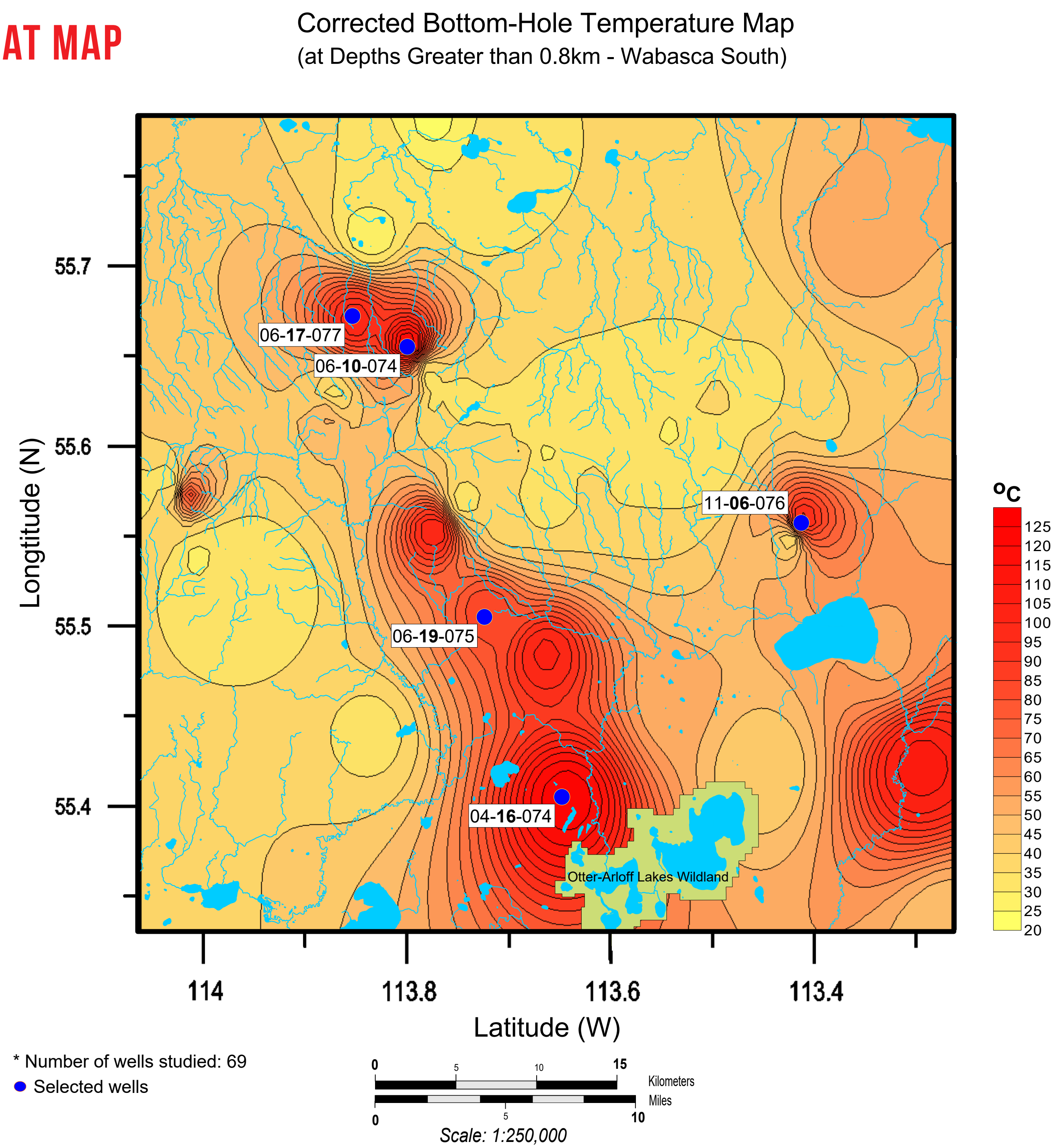
The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

RESEARCH RESULTS: WABASCA (SOUTH)

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

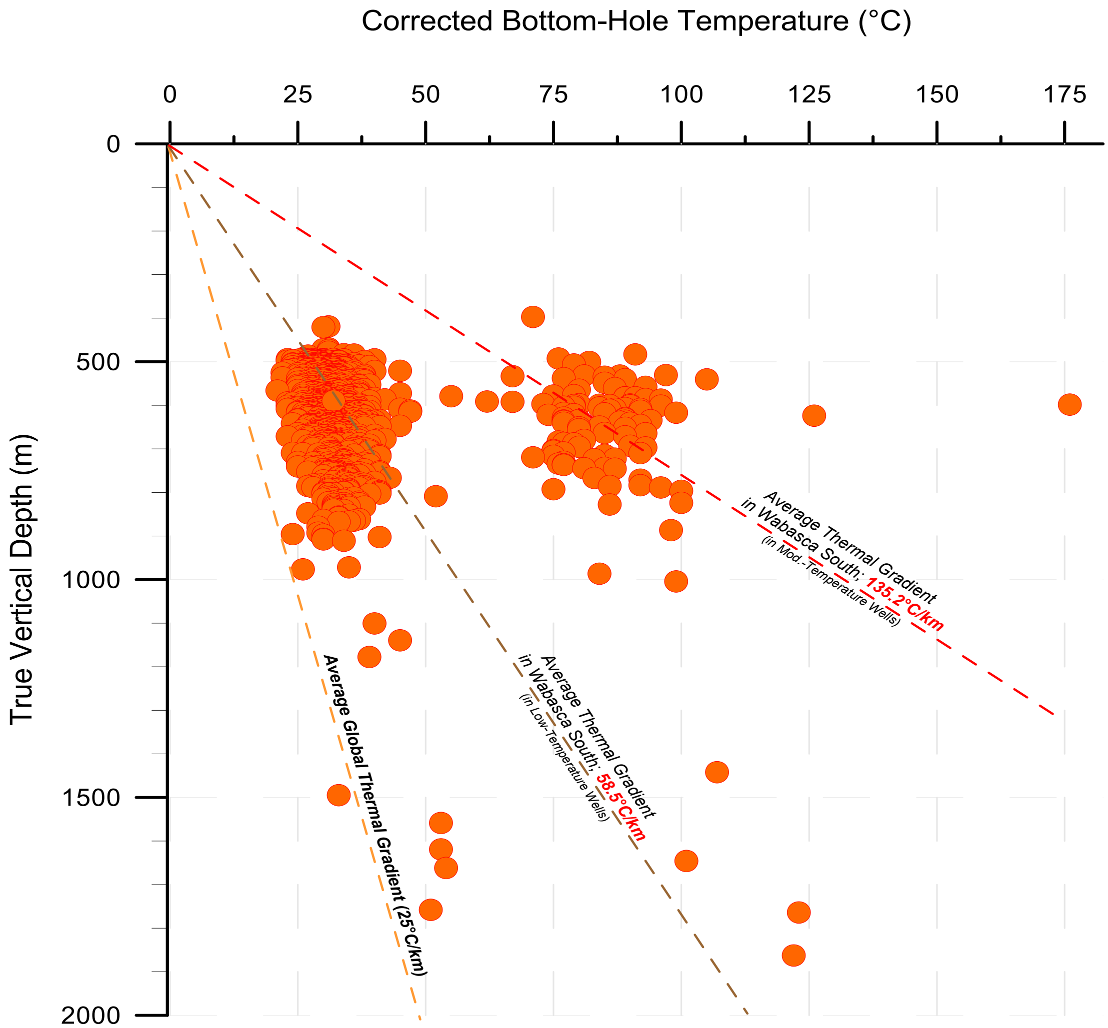
HEAT MAP



RESEARCH RESULTS: WABASCA (SOUTH)

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 5 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Leduc F. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/06-10-077-25W4/00	1862	-772.9	122	125	Imperial Oil Ltd
100/04-16-074-24W4/00	1763.3	-674.7	123	125	Devon Cda Corp
100/11-06-076-22W4/00	1003.5	-144.8	99	110	Husky Oil Oprtns Ltd
100/06-17-077-25W4/00	885.8	202.2	98	110	Cdn Nat Rsrcs Ltd
100/06-19-075-24W4/00	985.8	101.9	84	100	Cdn Nat Rsrcs Ltd

KEY TAKEAWAYS

- The identified productive geothermal formation in your area is the **Leduc** formation.
- There are two sets of temperature measurements in your area: a low-moderate grouping with a gradient of **58.5ºC/km** and a moderate-high grouping with a gradient of **135.2ºC/km**.
- There is potential for **direct use and/or power generation** activities in the study area

RECOMMENDATION & NOTES

Our study of the area south of Wabasca has uncovered factors that may be beneficial for geothermal activity. The recorded geothermal formation in the study area has a moderate thickness (150m) and may contain enough fluid to sustain geothermal activities. Though the recorded temperatures are not high enough to support power generation, the majority of wells with temperature measurements are quite shallow and are likely to produce higher temperatures at 2km or deeper. It is strongly recommended that a further, in-depth investigation of the geothermal potential within the study area be conducted that seeks to validate this initial temperature gradient and geological data in deeper wells, map fluid flows within target formations, and create energy potential models to assess the magnitude and viability of this opportunity.

September 25, 2018

Geothermal Analysis

Wembley

Study by Terrapin Geothermics

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

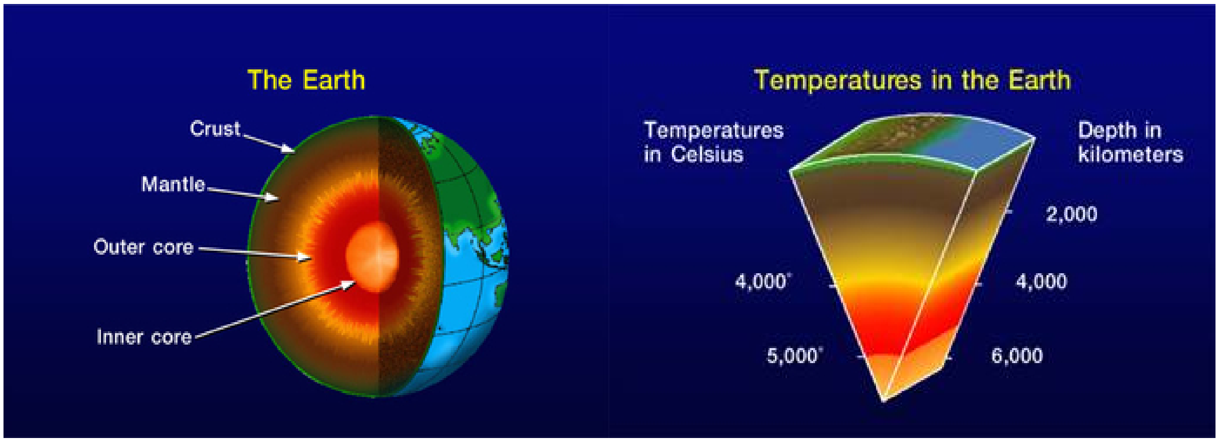
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

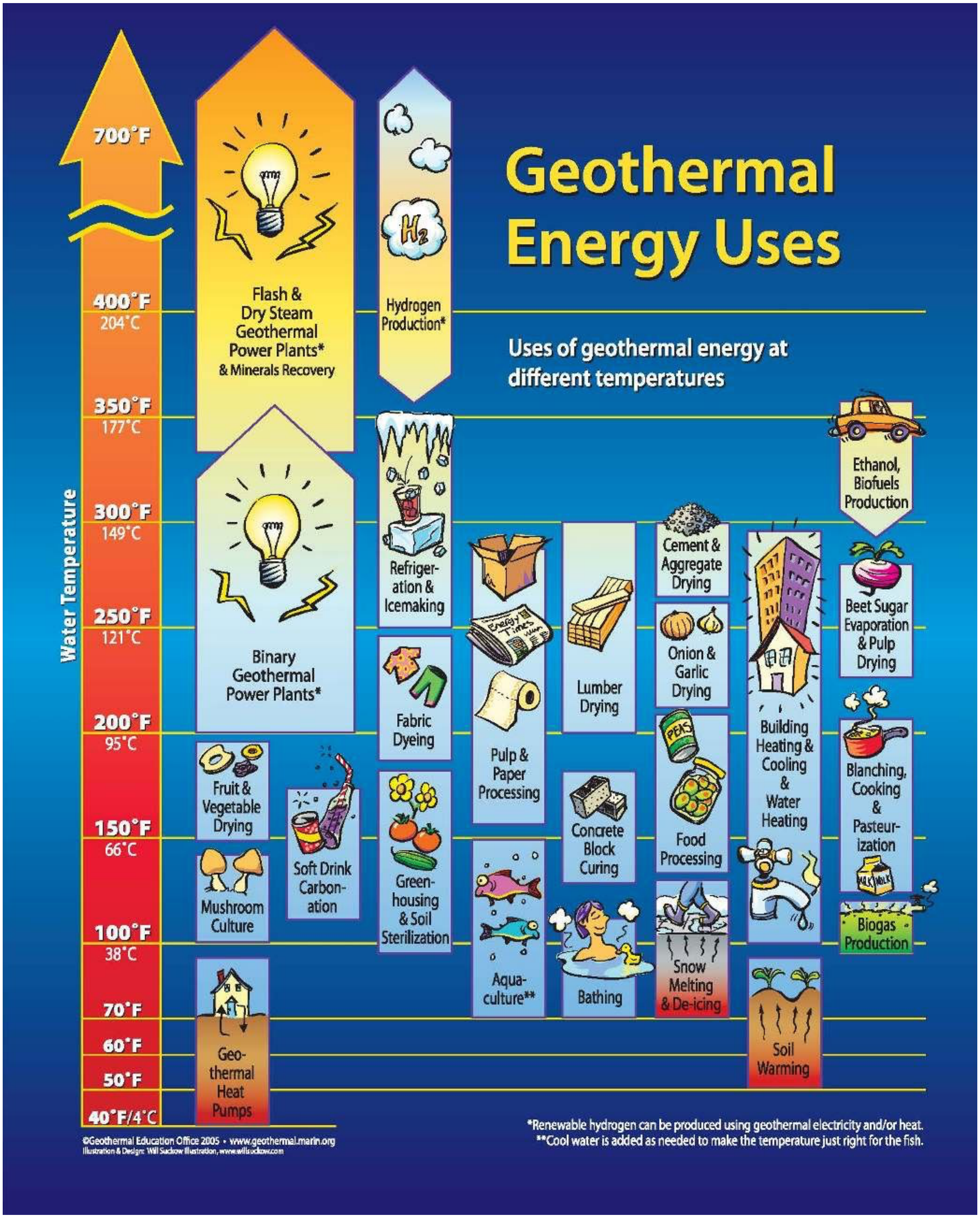
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180^{o}C and above), medium (100-180^{o}C), and low (80-100^{o}C) temperature resources with fluids under 80^{o}C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235^{o}C or above); flash plants (turning geothermal fluids of at least 150^{o}C into steam to drive a turbine); and binary power plants (using hot waters above 80^{o}C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180^{o}C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

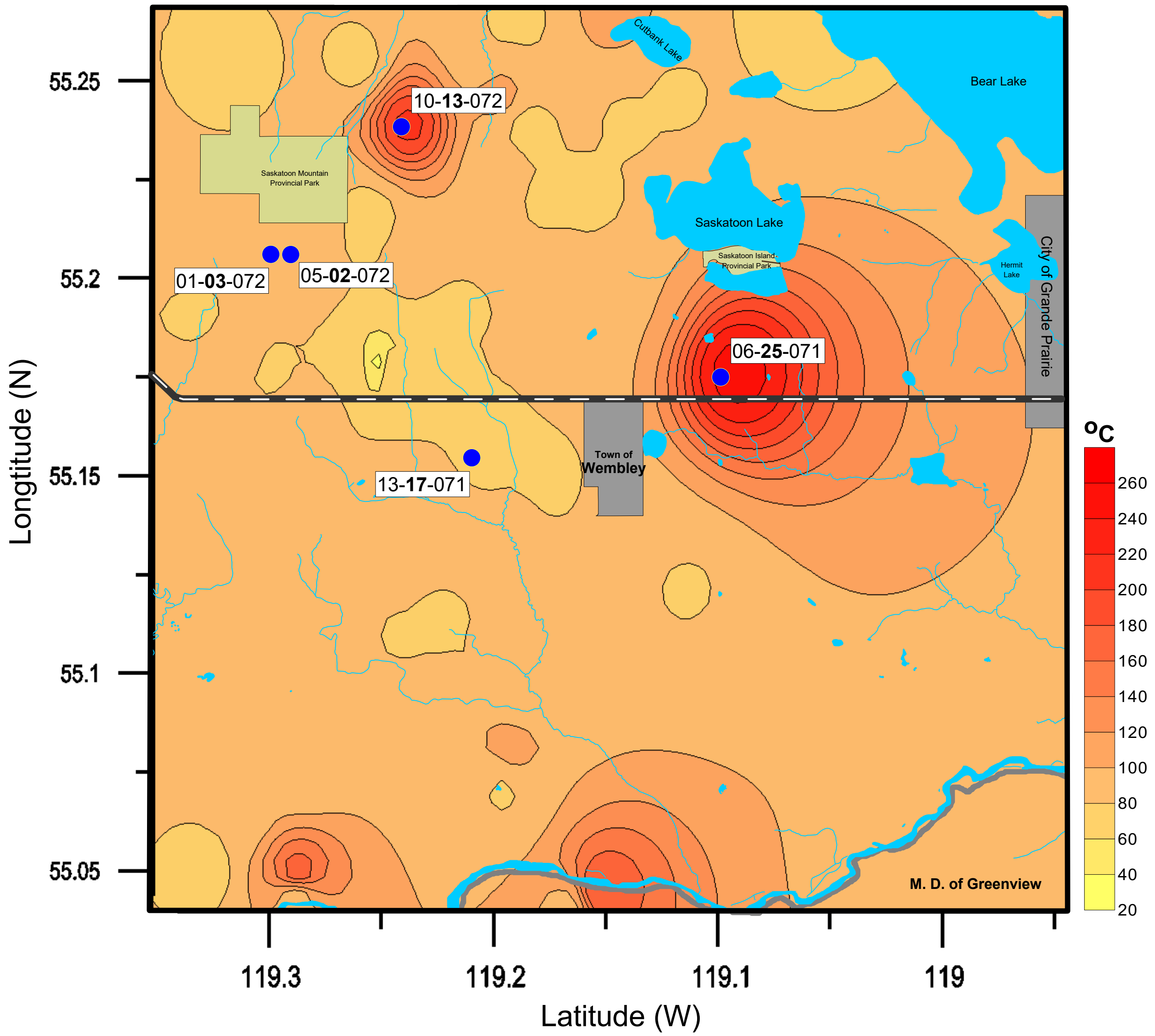
RESEARCH RESULTS: WEMBLEY

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

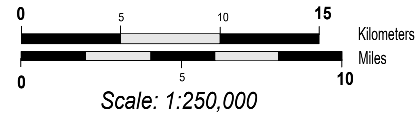
HEAT MAP

Corrected Bottom-Hole Temperature Map
(at Depths Greater than 2.4km - Town of Wembley)



* Number of wells studied: 74

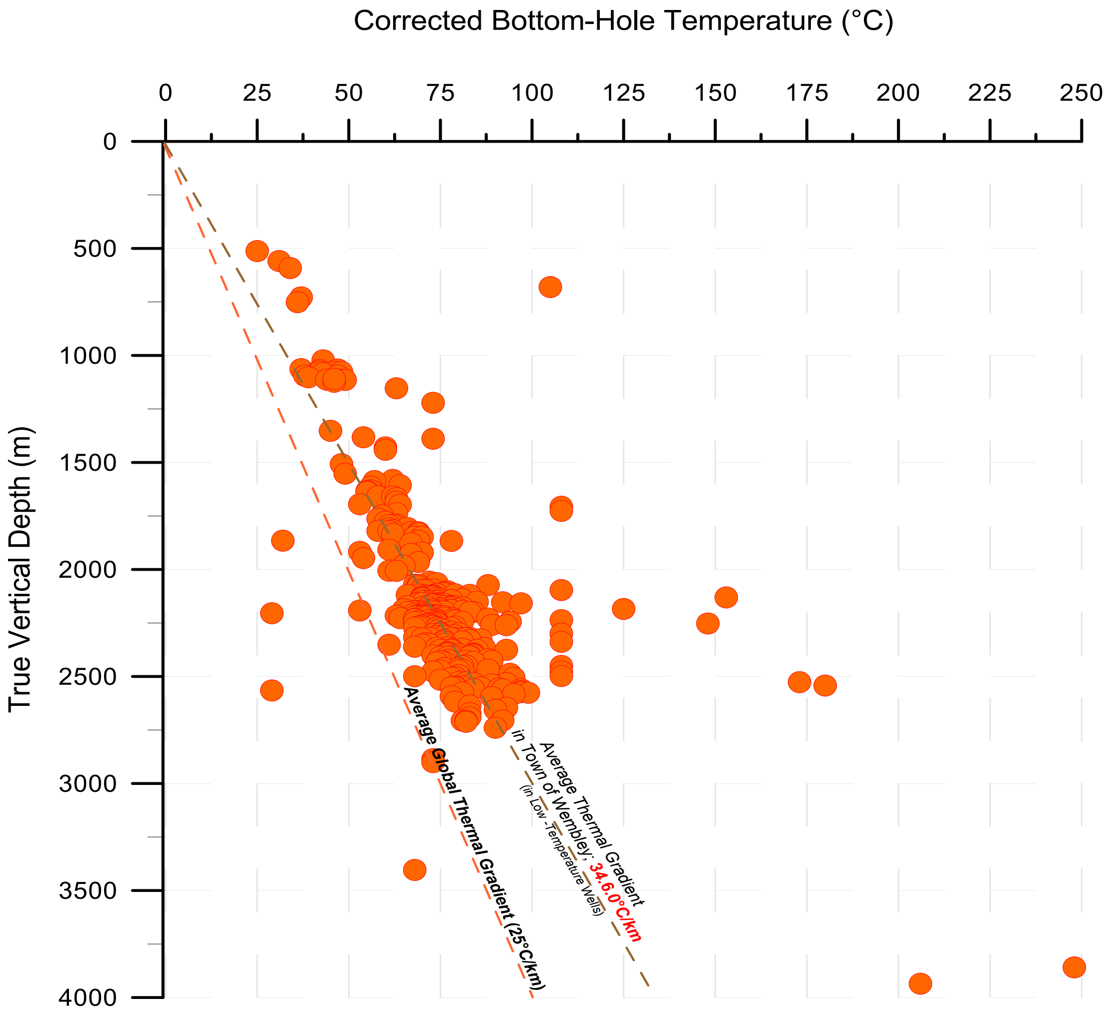
● Selected wells



RESEARCH RESULTS: WEMBLEY

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 5 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Leduc F. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/06-25-071-08W6/00	3857.8	-163.1	248	250	Suncor Enrg Inc(2)
100/10-13-072-09W6/00	3934.2	-239.3	206	210	Cdn Nat Rsrcs Ltd
100/13-17-071-08W6/00	2884.6	809.2	73	100	Longshore Rsrcs Ltd
102/01-03-072-09W6/00	2738.2	955.3	90	130	Cdn Nat Rsrcs Ltd
100/05-02-072-09W6/00	2710.6	983.7	82	120	Encana Corp

KEY TAKEAWAYS

- The identified productive geothermal formation in your area is the **Leduc** formation
- The temperature gradient in the area is **34.6ºC/km**. That is **38% higher** than the global average
- There is potential for **direct-use** activities in the study area

RECOMMENDATION & NOTES

Our investigation of the town of Wembley has uncovered excellent temperature readings to the northeast of the town that may support direct-use. There are consistently superior temperature readings that increase with well depth. As well, the Devonian strata has a moderate thickness (550m), and the identified productive geothermal formations in the study area average 163m thick. We recommend that the town undertake temperature validation activities, map the fluid flows within target formations, and create detailed thermal energy potential models to provide a basis for understanding the heat-use opportunities in the area. This knowledge can provide direction for future land use planning and development activities.

September 25, 2018

Geothermal Analysis

Whitecourt

Study by Terrapin Geothermics

For further information,
contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above 0^{o}C.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

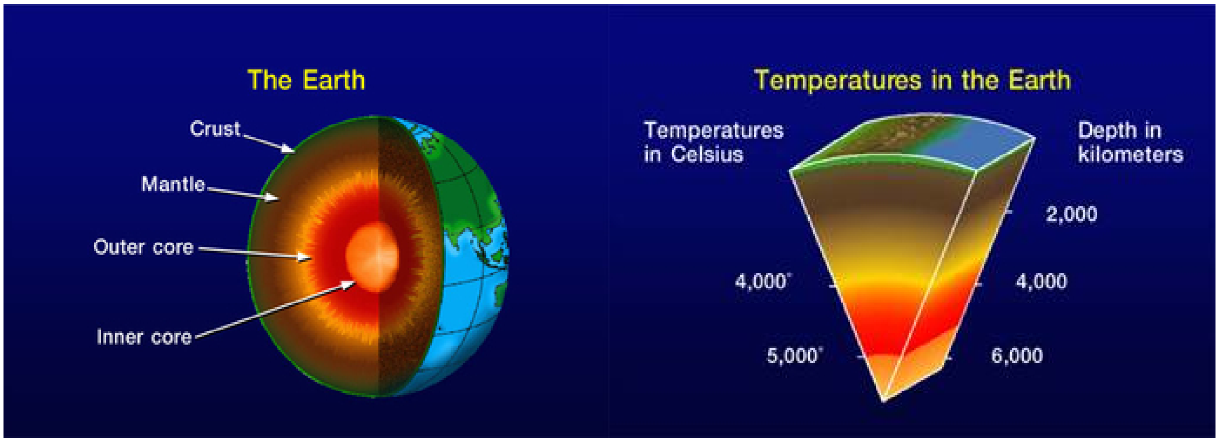
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

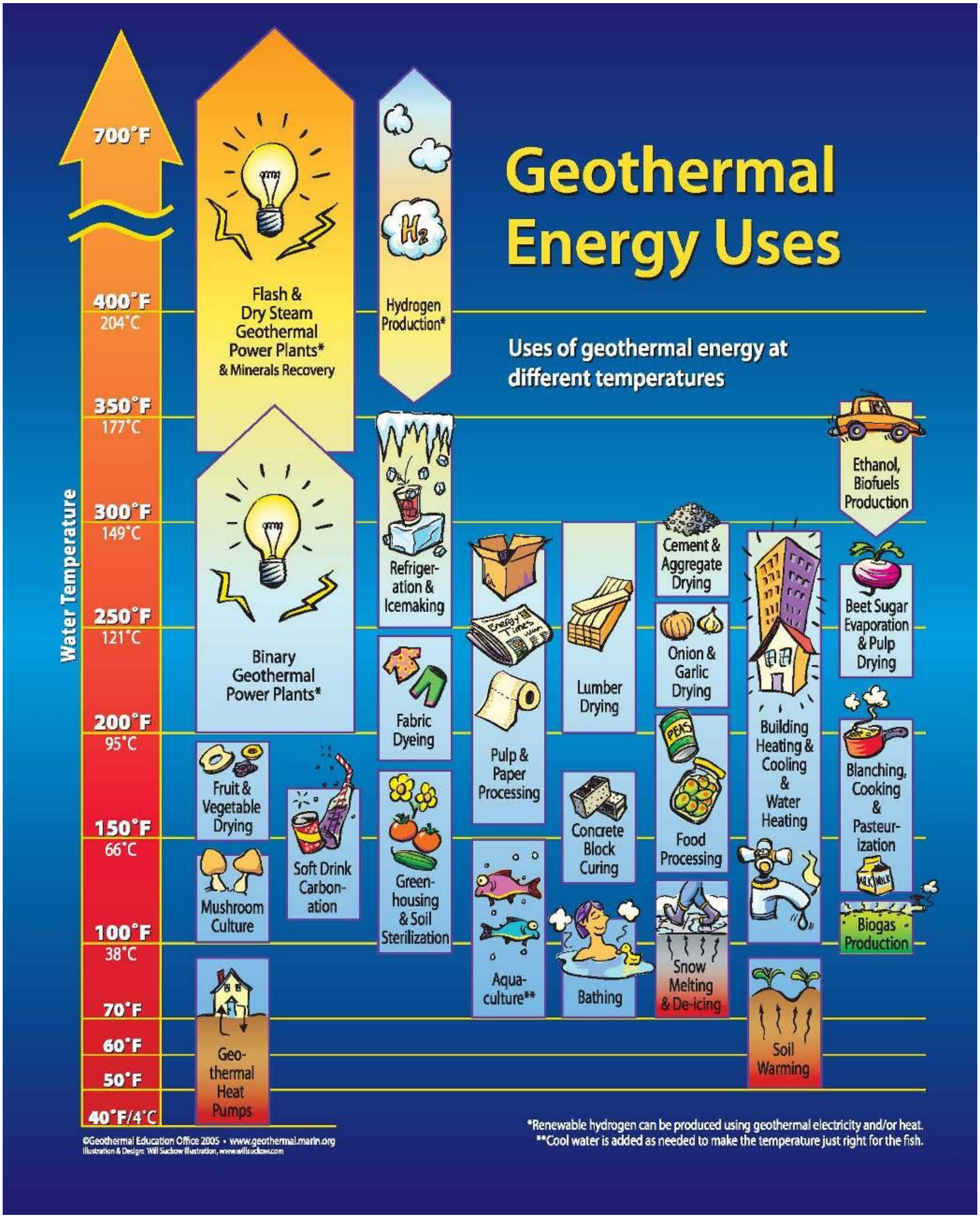
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth’s surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton’s Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

“Direct use” refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland’s homes and the district heating utility in Reykjavik serves approximately 60% of Iceland’s population.[1] A further example of direct use is the 5,000-acre Oserian Development Company’s flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160^{o}C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

---

[1] Gunnlaugsson, Einar et al., “85 Years of Successful District Heating in Reykjavík, Iceland”, *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180^{o}C and above), medium (100-180^{o}C), and low (80-100^{o}C) temperature resources with fluids under 80^{o}C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235^{o}C or above); flash plants (turning geothermal fluids of at least 150^{o}C into steam to drive a turbine); and binary power plants (using hot waters above 80^{o}C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180^{o}C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

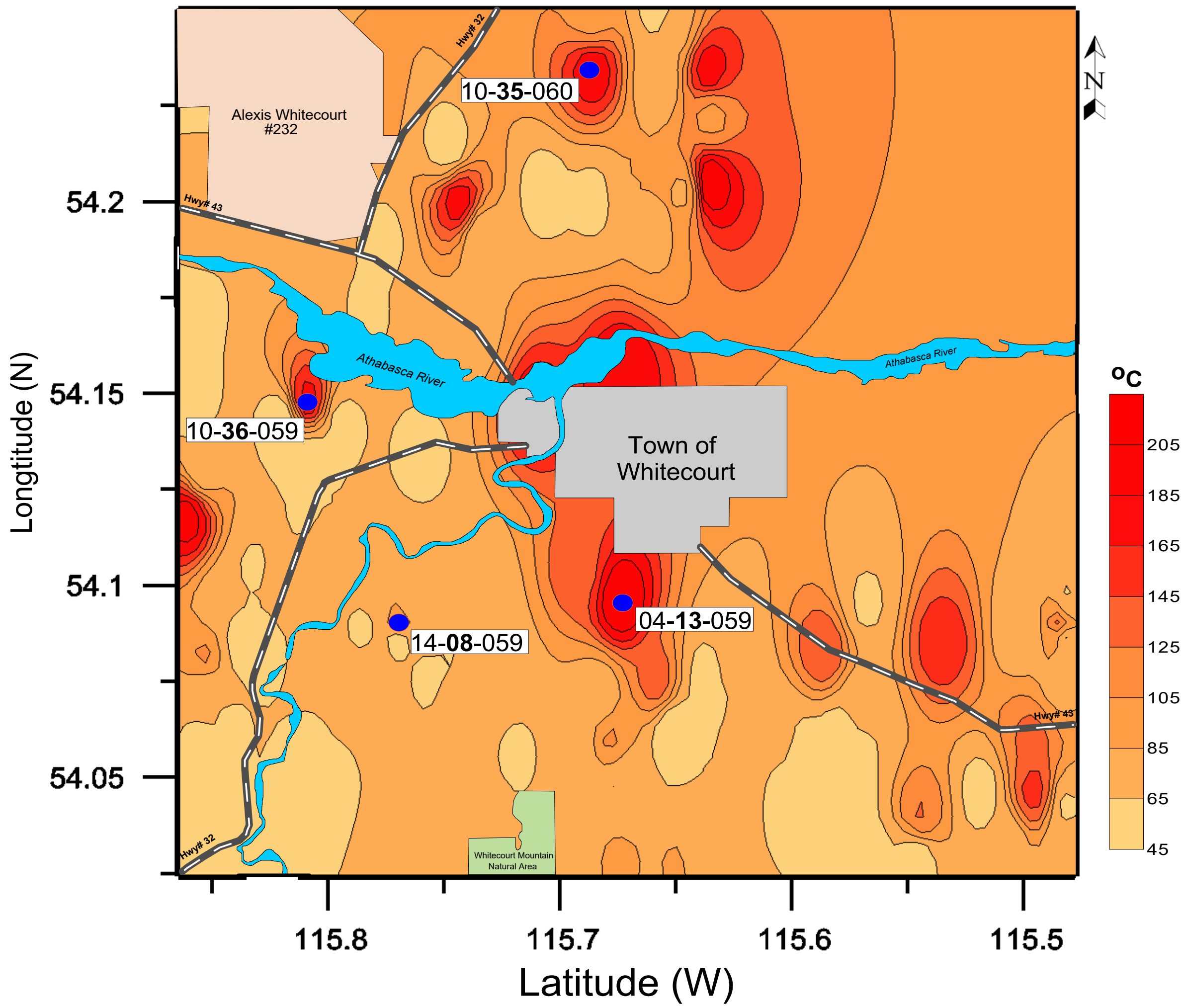
RESEARCH RESULTS: WHITECOURT

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

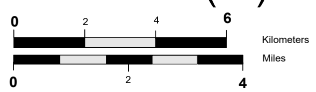
HEAT MAP

Corrected Bottom-Hole Temperature Map
(at Depths Greater than 1.7km - Town of Whitecourt)



* Number of wells studied: 125

Selected wells

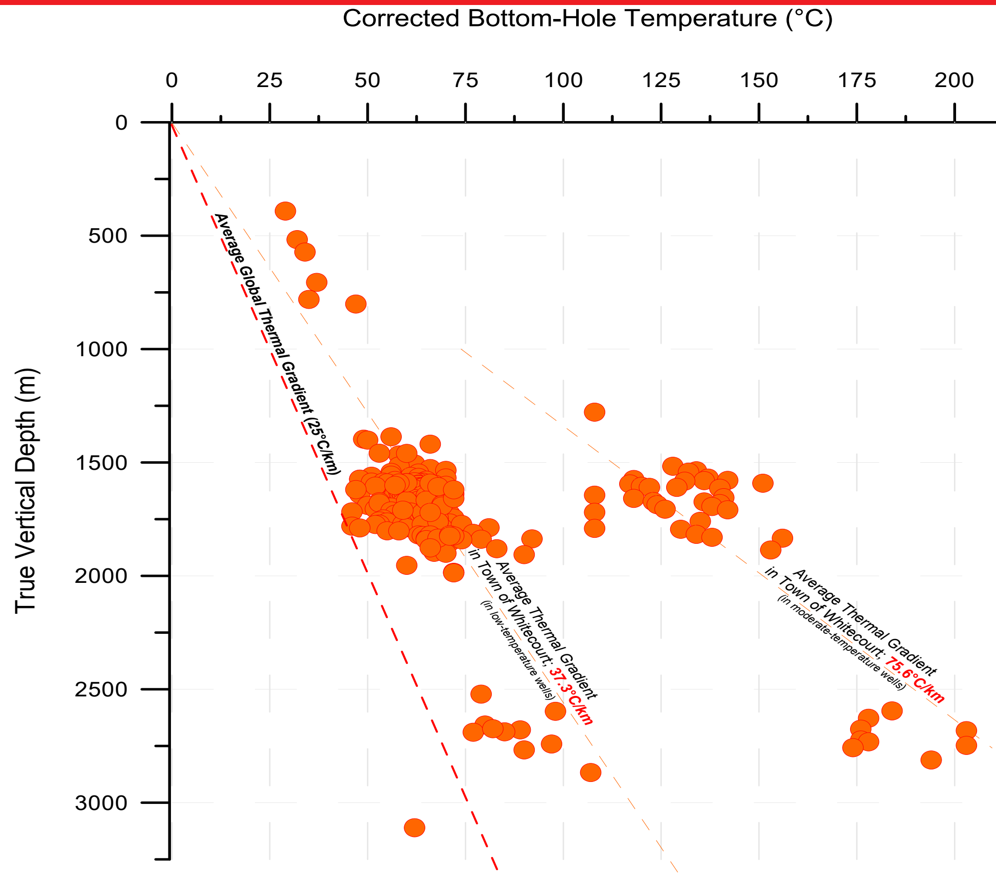


Scale: 1:150,000

RESEARCH RESULTS: WHITECOURT

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 4 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Swan Hill F. (m)	Corrected Bottom-Hole Temperature (°C)	Expected T. at Base of the Target Formations (°C)	Current Operator
100/04-13-059-12W5/00	2746.2	-55.2	203	215	Devon Cda Corp
100/10-35-060-12W5/00	2730.4	-123.2	178	200	-
100/10-36-059-13W5/00	2756.3	-139.9	174	200	Outlier Rsrcs Ltd
100/14-08-059-12W5/00	2865.7	-172.9	107	120	Progress Enrg Cda Ltd

KEY TAKEAWAYS

- The ideal formation for geothermal production in your area is the **Swan Hills** formation.
- There are two temperature data sets surrounding the town of Whitecourt. The low-moderate data set indicates a temperature gradient of **37.3ºC/km** with an average bottom hole temperature of **62ºC**. The moderate-high data set shows a gradient of **75.6ºC/km** with an average bottom hole temperature of **142ºC**.
- The moderate-high data set indicates the potential for **geothermal power generation** in the Whitecourt area.

RECOMMENDATION & NOTES

Our research of Whitecourt and the surrounding area has identified two distinct data sets related to Bottom Hole Temperature measurements: a low-moderate grouping and a moderate-high temperature grouping. The moderate-high grouping is amongst the strongest geothermal potential that our geology team has discovered in Alberta and the linear pattern in the distribution of hotter wells is indicative of possible geological anomalies in the area. It is very strongly recommended that Whitecourt pursue further research in this area. Specific studies should expand the scope of work to the surrounding areas, seek to validate this initial temperature and geological data, map fluid flows within target formations and create detailed energy potential models to assess the magnitude and viability of this seemingly large opportunity.

September 25, 2018

Geothermal Analysis

Wabasca #166-166D

Study by Terrapin Geothermics

For further information,
contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above 0^oC.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

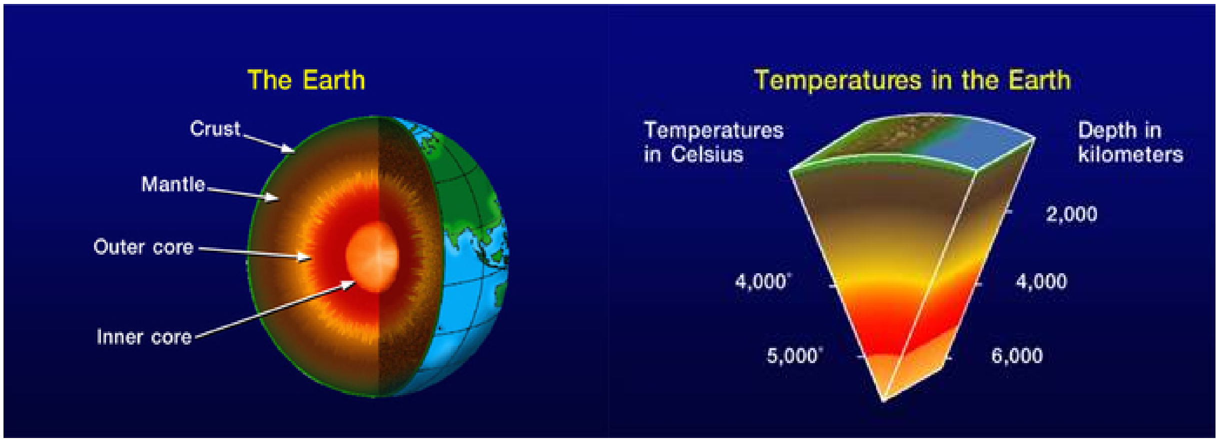
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

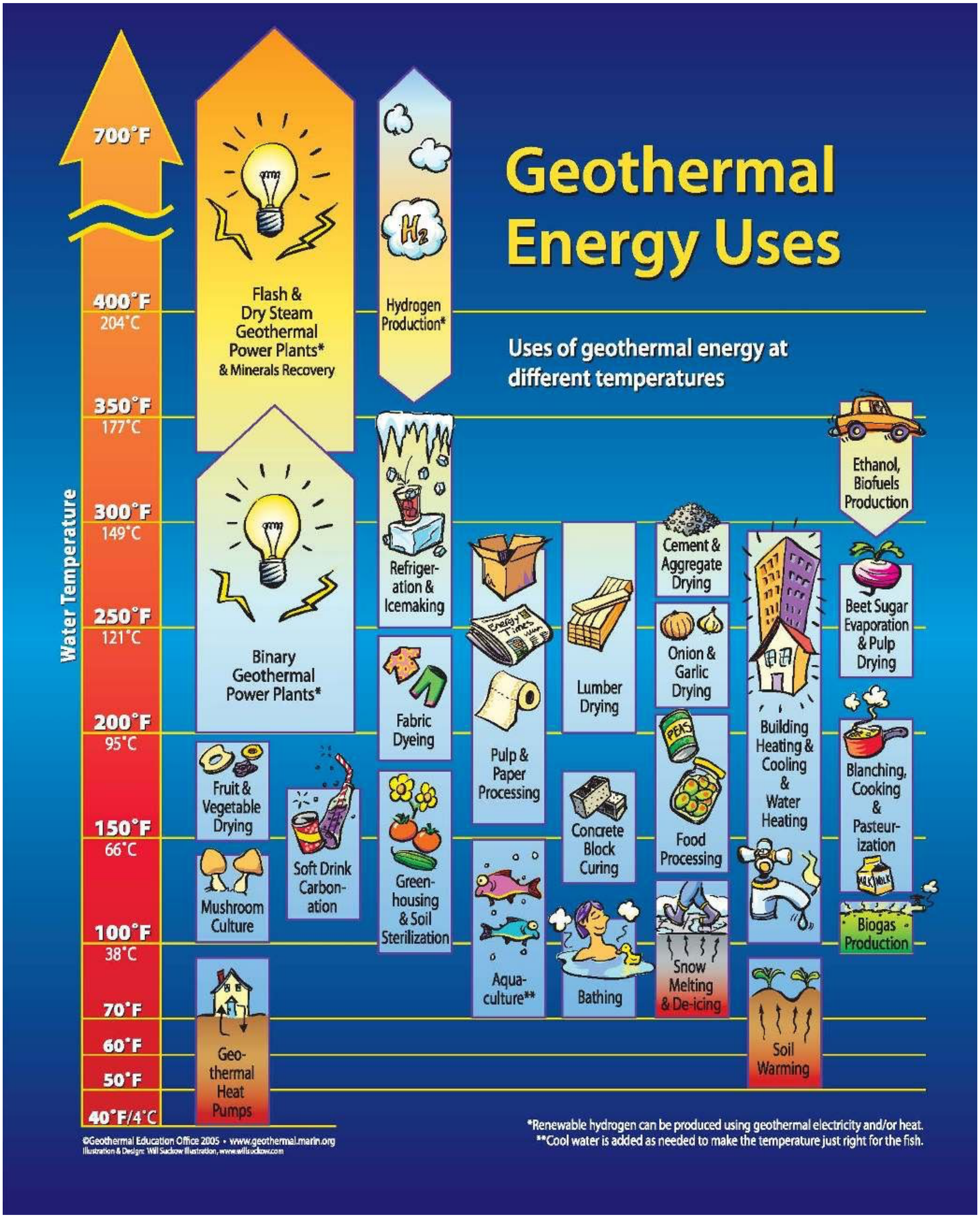
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160^{o}C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180°C and above), medium (100-180°C), and low (80-100°C) temperature resources with fluids under 80°C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235°C or above); flash plants (turning geothermal fluids of at least 150°C into steam to drive a turbine); and binary power plants (using hot waters above 80°C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180°C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

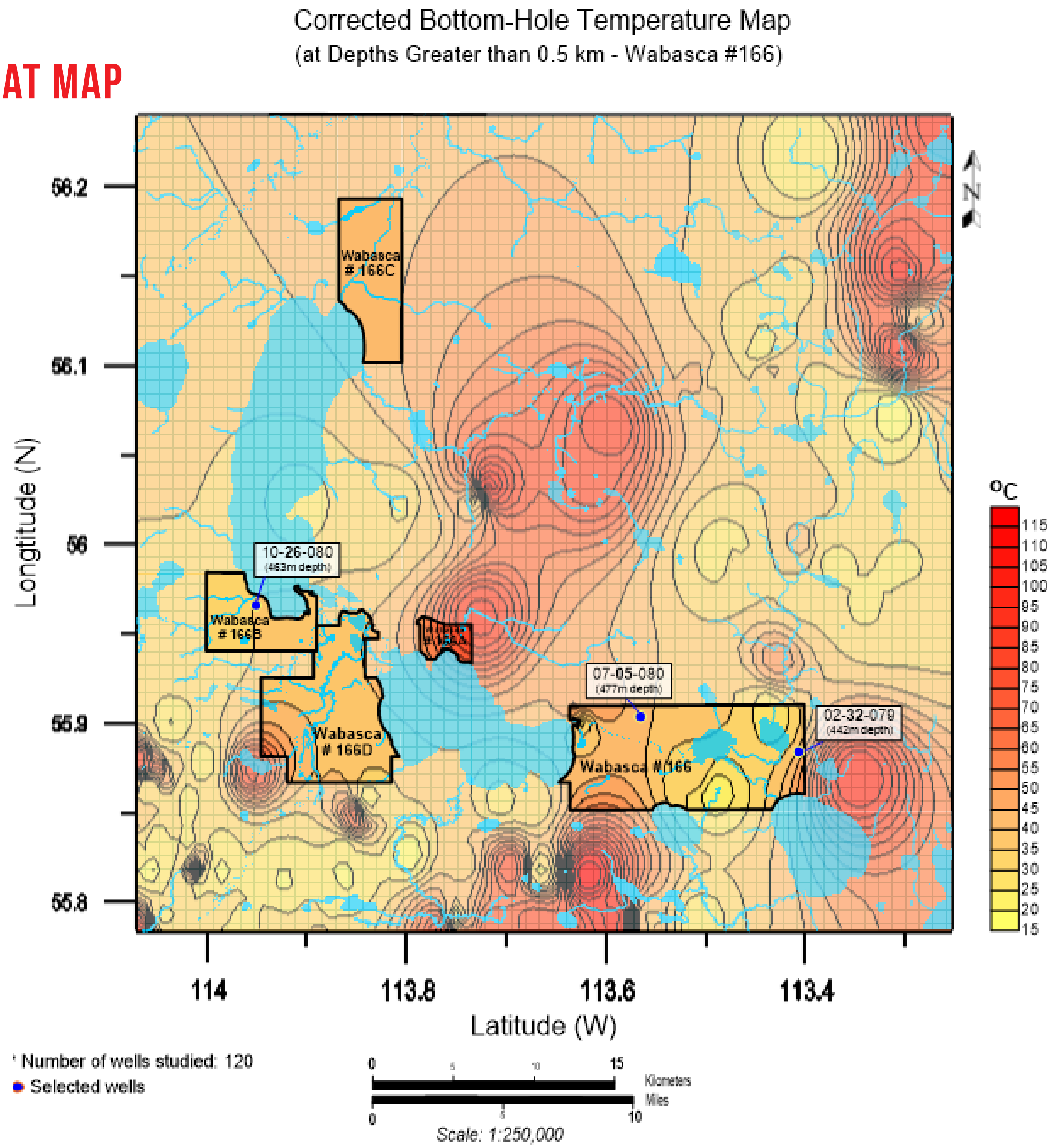
The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

RESEARCH RESULTS: WABASCA #166-166D

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

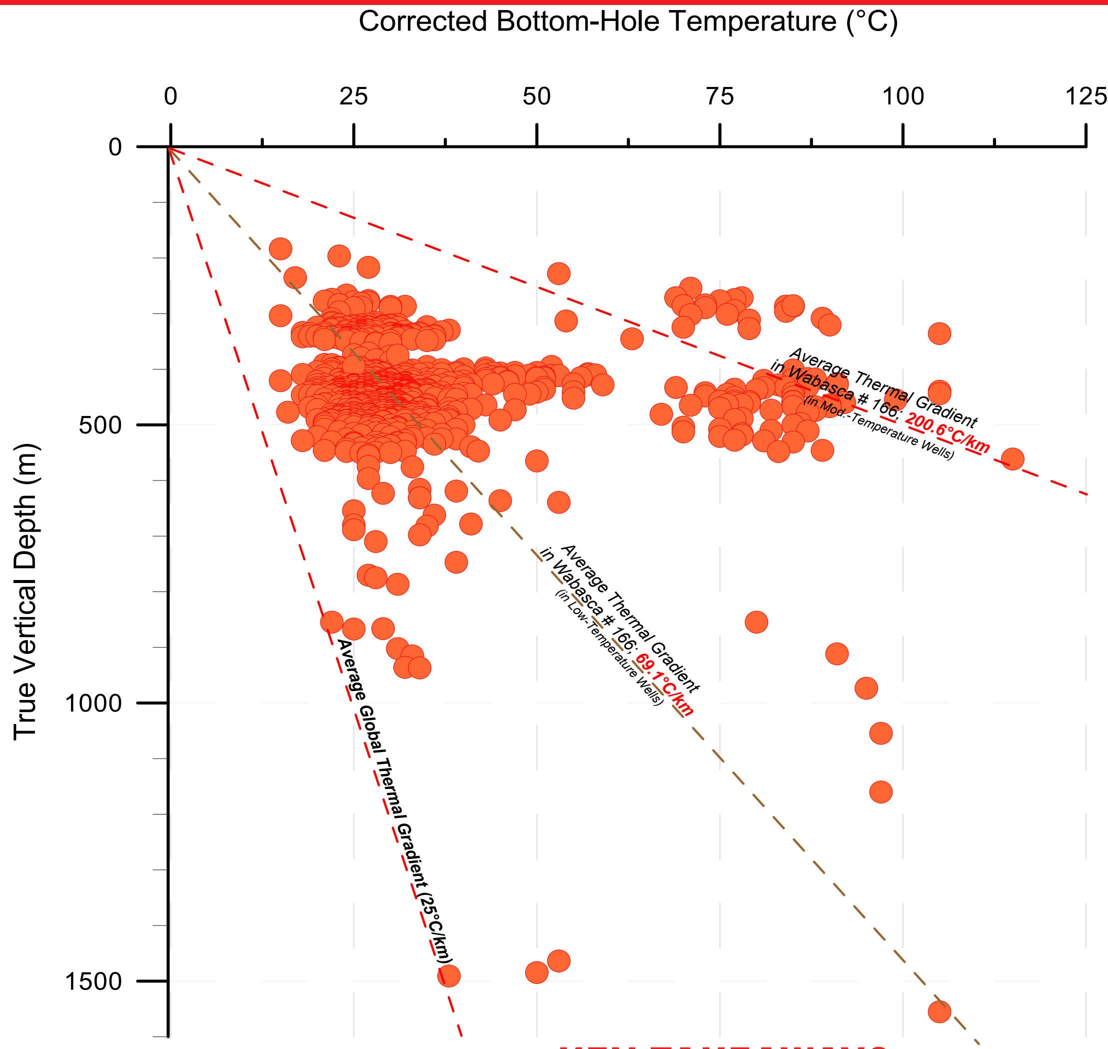
HEAT MAP



RESEARCH RESULTS: WABASCA #166-166D

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 3 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Granite Wash F. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/02-32-079-22W4/00	439	1007	105	150	Husky Oil Oprtns Ltd
100/10-26-080-26W4/00	459.4	986.6	92	120	ExxonMobil Cda Ltd
100/07-05-080-23W4/00	473	973	82	100	ExxonMobil Cda Ltd

KEY TAKEAWAYS

- The identified productive geothermal formation in the subject area is the **Granite Wash** formation
- There are two groupings of temperature measurements leading to indicated temperature gradients of **69.1ºC/km** and **200.6ºC/km**. These numbers show significant influence from the shallowness of the wells used as data points.
- There is potential for **geo-exchange** activities and possible **direct use** activities in the study area

RECOMMENDATION & NOTES

Our study of the Wabasca area has uncovered factors that are detrimental to large-scale geothermal development. First, the only identified productive formation is quite thin (2m to 25m) and may not contain enough fluid for geothermal activities. As well, the majority of wells in the area are drilled to depths less than 750m. This shallowness means that temperature readings are likely to have been influenced by the thermal conductivity of shallow rock layers, potentially anomalous temperature readings, improper measurement techniques, or data entry errors and has led to a severe overestimation of the temperature potential. Temperature readings in the deeper wells should be verified for their direct-use potential. In the interim, it is recommended to investigate the opportunity to build geo-exchange systems to take advantage of the relatively stable temperature below the frostline.

September 25, 2018

Geothermal Analysis

Woodlands County

Study by Terrapin Geothermics

For further information, contact:

Sean Collins, President
780.232.0339
sean@terrapingeo.com

Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above 0^{o}C.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

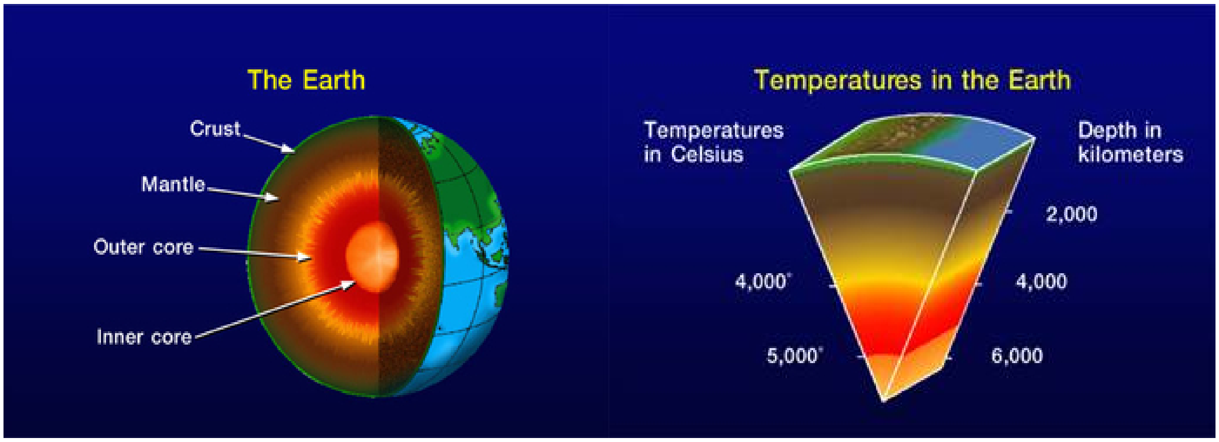
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

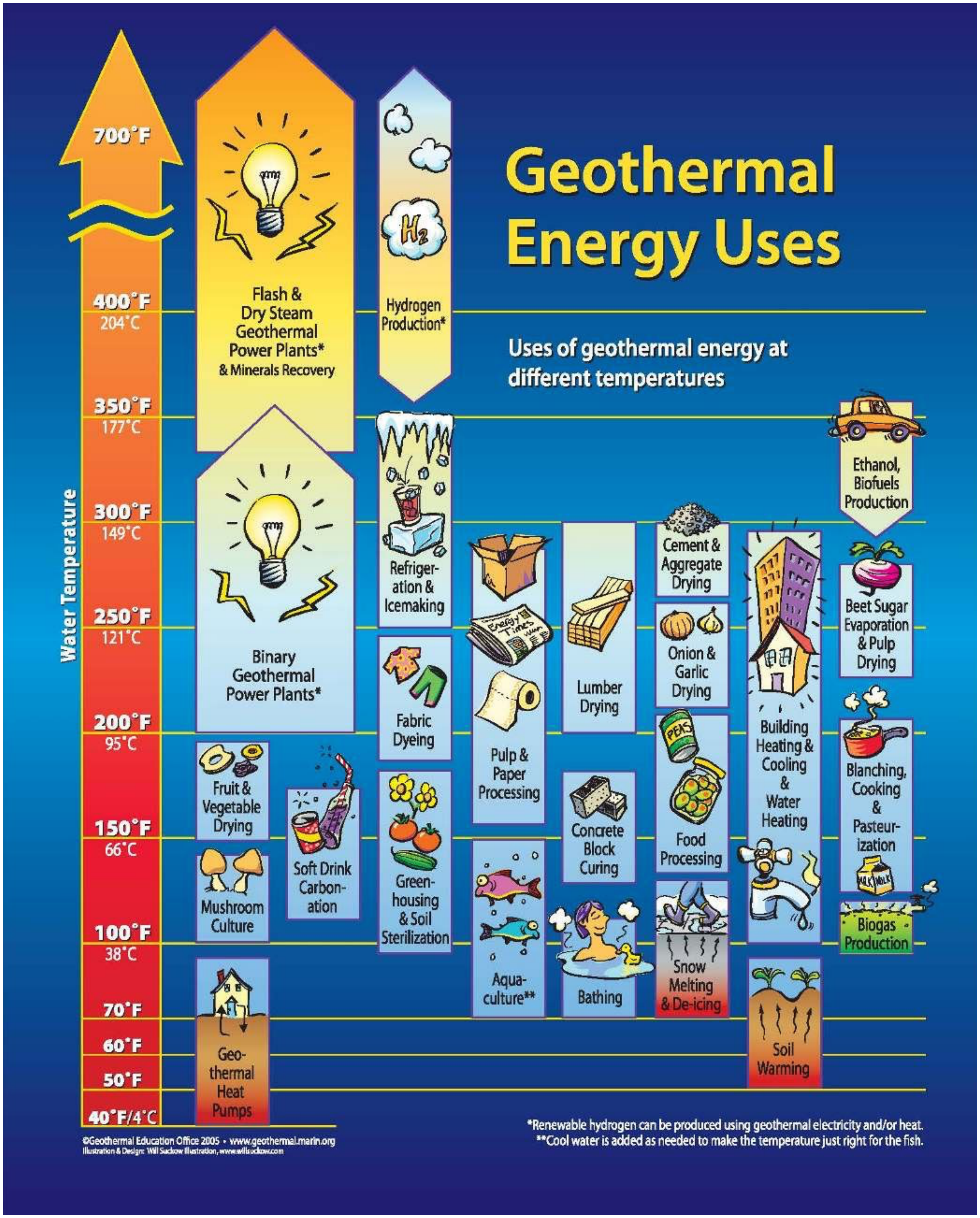
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160°C and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180°C and above), medium (100-180°C), and low (80-100°C) temperature resources with fluids under 80°C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235°C or above); flash plants (turning geothermal fluids of at least 150°C into steam to drive a turbine); and binary power plants (using hot waters above 80°C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180°C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

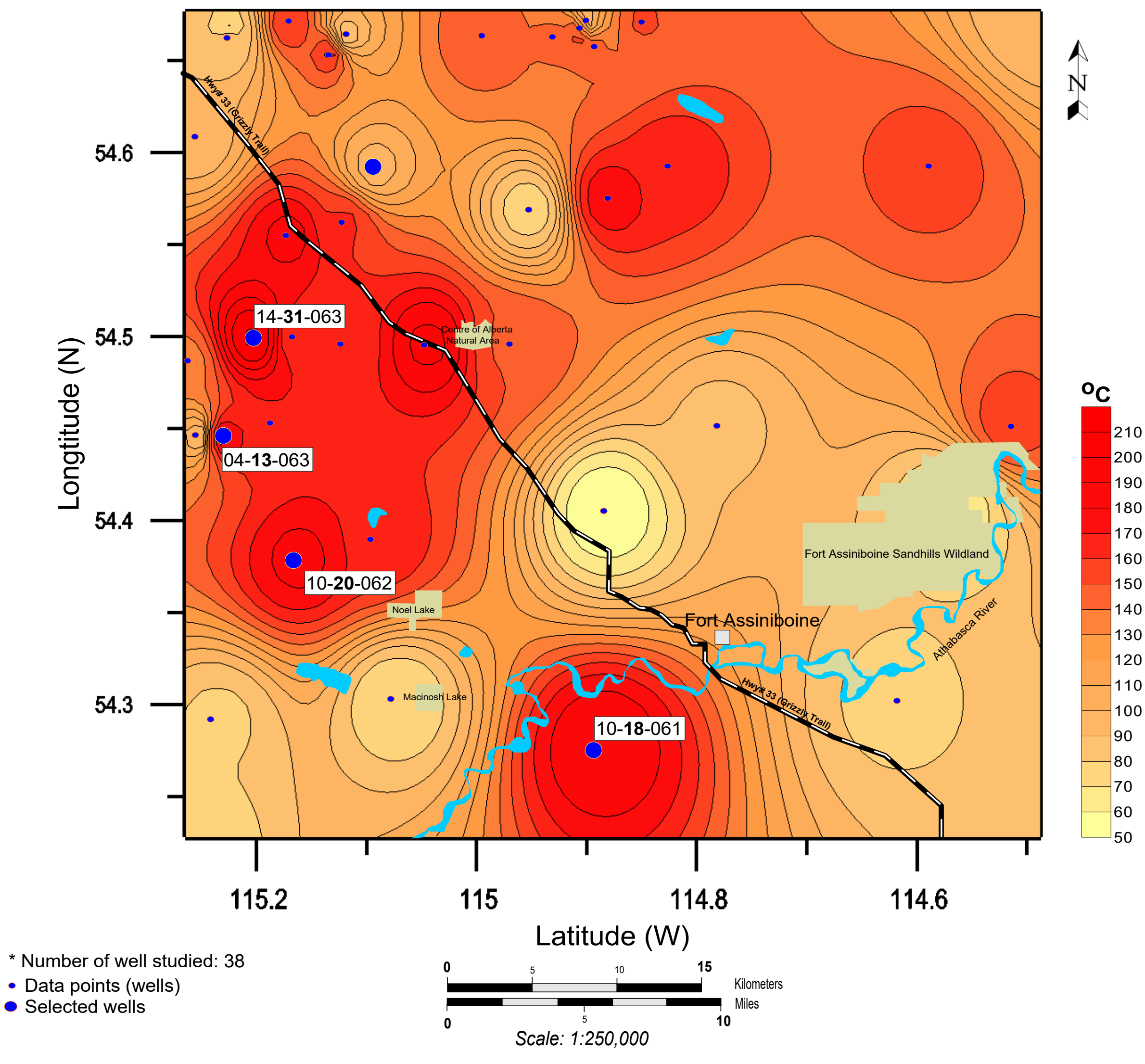
RESEARCH RESULTS: WOODLANDS COUNTY

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

HEAT MAP

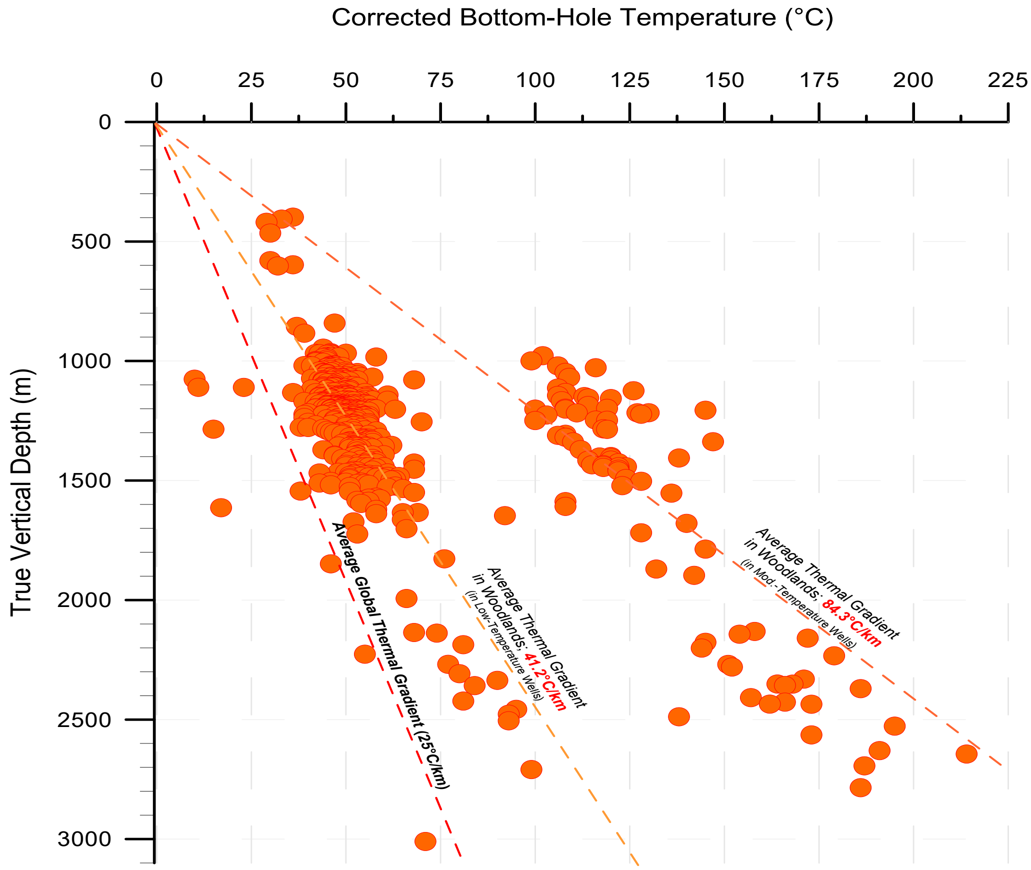
Corrected Bottom-Hole Temperature Map
(at Depths Greater than 2km - Woodlands County)



RESEARCH RESULTS: WOODLANDS COUNTY

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 4 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Granite Wash F. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected Temperature at the Base of Target Formations (˚C)	Current Operator
100/10-18-061-06W5/00	2628.7	-474	188	200	Suncor Enrg Inc (2)
100/14-31-063-08W5/00	2643	-321.9	211	220	Imperial Oil Ltd
100/04-13-063-09W5/00	2692.4	-288.1	184	200	Imperial Oil Ltd
100/10-20-062-08W5/00	2783.8	-497.7	183	200	ExxonMobil Cda Ltd

KEY TAKEAWAYS

- The productive geothermal formation underlying the study area is the **Granite Wash formation**
- There are two temperature data sets in the study area. The low-moderate data set indicates a temperature gradient of **41.2°C/km** with an average bottom hole temperature of 50.6°C. The moderate-high data set shows a gradient of **84.3°C/km** with an average bottom hole temperature of 131.7°C. These are both significantly higher than world average.
- There is strong potential for **geothermal power generation** in the study area.

RECOMMENDATION & NOTES

Our research for Woodlands County, focused on an area surrounding Fort Assiniboine, has identified two distinct temperature data sets: a low-moderate and a moderate-high temperature grouping. The moderate-high grouping is amongst the strongest geothermal potential that our geology team has discovered in Alberta. The elliptical and elongated patterns in the distribution of similar temperature wells is indicative of possible geological anomalies in the area. It is very strongly recommended that Woodlands County pursue further research in this area. Specific studies should expand the scope of work to the entire County to discover other potential temperature anomalies, seek to validate this initial temperature and geological data, map fluid flows within target formations, and create detailed energy potential models to assess the magnitude and viability of this seemingly large opportunity.